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REPULSIVE FORCES IN NATURE.*

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A body casually dropped from the hand falls to the ground under the attractive force of the Earth's gravity. This same force extends to the greatest heights. Travelers notice that it operates at the tops of high mountains; and we may see it at work in the clouds, if we observe the falling of objects from balloons. It extends even to the Moon, and holds our satellites in its orbit about the Earth, as Newton proved by his great discovery in the year 1687. He also showed that the gravity of the Sun holds the Earth, planets and comets in their orbits, and that the gravity of planets like Jupiter and Saturn keeps their satellites revolving in an orderly manner about their own centers. In the same way double and multiple stars observed in different parts of the sky are seen to be moving about one another. It is now demonstrated that the force which controls their motions is the same gravitation which we see at work here upon the Earth. Sir Isaac Newton was the first to thoroughly investigate this grand law of nature, and under the conditions expressed in Kepler's laws he proved it to be universal.

If a mass of one kilogram be dropped from a height of 424 meters, it produces enough heat by its fall under the action of gravity to raise the temperature of a kilogram of water one degree Centigrade. This relationship between the motion of a body and the temperature to which it would be raised by falling is known as the mechanical equivalent of heat, and was discovered by Joule about 1850. Enough such masses descending upon the Earth would render its surface quite warm; but as very little matter actually falls upon our globe, we see the effects of this law by which energy of motion is converted into heat, chiefly in the Sun, where all the particles are slowly falling towards its center, and by giving up their potential energy thus maintaining its tremendous temperature. The shrinkage of the Sun's volume under the force

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of its own gravitation, which at the solar surface is twenty-eight times that upon the Earth, supplies the energy for the enormous flood of heat and light continually radiated into space. The maintenance of the Sun's radiation, as well as the curvature of the orbits of planets and comets, is due to the attractive force of universal gravitation. The cause of this force is still wholly obscure, though it has been searched for in vain by the acutest minds of the past two centuries; yet the law of its action given by Newton represents accurately all the phenomena of Nature. This wonderful law of attraction, applicable to the starry heavens in all their immensity, is admittedly the most important discovery ever made by the mind of man!

It is now two hundred and fifteen years since Sir Isaac Newton published the law of gravitation in his immortal *Principia*, which explains with all the rigor characteristic of the greatest philosopher of all time, the principal effects of universal gravitation upon the figures and motions of the heavenly bodies.

It is shown by Newton that gravitation is an attractive force operating not between bodies *en mass*, but between the several particles of solid matter of which they are composed; and the labors of mathematicians during the past two centuries have been devoted to tracing out the full effects of Newton's law under the varied conditions of the material universe. Though the law of gravitation is simple, its effects are very complicated; and consequently it will perhaps never be possible to determine the full effects of this force upon the motion of a system, composed of numerous bodies, such as a star cluster. In the Solar System, the arrangement of which is orderly and simple, and among the double and triple stars observed in the immensity of space, the conditions are such that a mathematician may determine the effects of the mutual attractions of the bodies, but the labor in some cases is very great.

This development of mathematical astronomy has occupied a large share of the world's genius during the past two centuries, and it is not too much to say that the results achieved are justly considered to be the noblest monument of the human intellect. It may be said that it is now possible to trace the exact places of the Sun, Moon and planets through past and future centuries, with such accuracy that if an observer were present in those epochs, he could discover scarcely any errors in the computations of the astronomer. For something like 2000 years in the past, and as great a period in the future, the computations of mathematical astronomy may be relied upon with confidence. Thus

we may now compute the places of the planets and the Sun and Moon much more accurately than they were actually observed by the Greeks and Romans.

In the year 1854 it was shown by Helmholtz, that the radiation of the Sun and stars is derived from the energy of the gravitational shrinkage of their masses,—that the Sun gives out its enormous flood of heat and light in virtue of a small shrinkage in its radius of about 110 feet per year, and after some millions of years have elapsed will have become sufficiently dense that further shrinkage can not take place without lowering the temperature, so that darkness will follow. A similar life history is indicated for each of the millions of stars composing the stupendous arch of the Milky Way, which are self-luminous bodies constituted essentially like our Sun.

The attractive force of gravity thus tends to condense all stars into compact masses whose luminosity will eventually decline on account of increasing density, and after long ages the stellar universe from this cause alone would cease to shine.

Lord Kelvin has shown that there is in Nature also what is known as a dissipation of energy, by virtue of which every material system tends to run down. The energy of moving bodies obstructed by friction or collision tends to pass into heat, and the energy of heat, even in the most perfect conceivable engine, cannot again be transformed into motion without loss, so that the potential and kinetic energy of the universe is being gradually exhausted in the development of heat. The activity and life of the Universe as expressed in the motion of its bodies thus tends to come to an end. All this is due to the attractive force of gravitation under the ordinary laws for the transformation of energy. The theory of energy has been especially studied during the 19th century, and in view of the present advanced state of science, it is not probable that any of the general laws now recognized will be radically altered by future discoveries. Thus the probable career of the physical Universe may be predicted with great confidence. The Universe viewed as a material system seems to be running down, from the gradual conversion of all the motion of the heavenly bodies into heat, with a tendency to uniform distribution of this low form of energy throughout all space.

The interesting question arises whether in Nature there are any important repulsive forces at work to counteract the condensing tendency of universal gravitation. Heretofore this question has been given little consideration; for the character of the repulsive

forces at work could only be surmised, and all the surmises thus far put forth have been rather tentative. But the mathematical proof by Professor James Clerk Maxwell, more than a quarter of a century ago, that light exerts a slight repulsive force upon the material bodies embedded in the ether, and the recent experimental verification and extension of his theory have added a new interest to the subject of cosmic repulsive forces.

The idea of repulsive forces in the heavens first occurred to astronomers in connection with the tails of comets, which were observed to point away from the Sun.

The appearance of a great comet moving about the Sun, with its tail pointing from that luminary is undeniably one of the most striking phenomena presented by the physical universe. The immense tail so often developed is not one solid whole, but made up of very minute particles, continually in motion, each acting independently of the others, and the whole appendage so excessively tenuous that faint stars are easily seen through its densest parts. An examination of the appearance of the head and tail and their mode of connection soon convinced the early observers that the tail is derived in the same way from the material of the head. It is vaporized or excited by the Sun's action upon the head, and as the matter thus volatilized rises towards the Sun, it is met by powerful repulsive forces, which cause it to stream back on all sides of the head, forming a hollow conical sheath. The dark center of this cone behind the nucleus contains very few particles, while its surface comparatively is so dense in such material, that the tail as a whole appears like a curved horn, hollow and dark in the center and bright on the edges. The horn-like tail is usually curved backward, owing to the combination of the forward motion of the comet with the repulsion of the particles of the tail from the Sun. Each particle as it leaves the head has the orbital motion peculiar to that point of the orbit where the separation took place under the influence of the Sun's repulsive force. Thus as the comet approaches the Sun, the tail lags behind, and is bent backward; while in receding from the Sun, after perihelion passage, it precedes the comet and is bent forward. When the comet passes very near the solar surface, as occasionally happens, the direction of the tail is reversed in a very few hours. No phenomenon of nature is more remarkable than this visible whirl of a comet's tail about the Sun.

As the head of the comet plunges on through the ether in the forward motion of the body in its orbit, the volatile matter which streams back to form the tail spreads behind it in much

the same way that the waves do after a boat propelled rapidly through smooth water. The tail splits on either side of the head but usually the two branches are not quite symmetrical, that on the preceding side being a little the brightest. The curvature of the whole tail is due to the three forces acting on the particles, namely, the gravitational acceleration along the radius vector drawn to the Sun, the forward motion of the comet along the tangent to the orbit, and the repulsive force emanating from the Sun's center. This force acts with different effects on different elements in the comet, and thus frequently produces several tails to the same head, each having its own peculiar curvature depending in some way upon the intensity of the repulsive force.

It is curious to notice how slowly our knowledge of comets has developed. The early astronomers, such as Appian, Cordan, and Tycho Brahé, supposed the tail of a comet to arise simply from the passage of the solar rays through the nebulosity of the head and compared the phenomenon to a beam of light transmitted into a dark chamber through a small aperture. They did not seem to remember that we see such a beam only by reflection from particles of dust suspended in the air; and hence in order that the tail of a comet may be visible out in space, it must be made up of particles which act likewise in reflecting the light of the Sun. The followers of Descartes imagined that the tails of comets were due to refraction which light from the comet's head suffered in the ether while passing to the eye of the observer; but as no prismatic coloration was noticeable about the comet, this theory was of course untenable. De Marian supposed the tail of a comet to be similar to the Aurora Borealis. Other persons supposed the tails to be composed of material similar to the nebulosity of the comet; and adopting Aristotle's distinction of heavy and light bodies, imagined the tail to recede from the Sun on account of the inherent levity of the material. It will be remembered that the Greeks, unable to account for the ascent of fire, smoke, vapor and other light substances, had imagined that each element seeks its proper place, and that some bodies are naturally light while others are heavy. Unsound mechanical theories of this kind were of course swept away with the triumph of the modern philosophy of Galileo and Newton.

Kepler supposed the whole comet to be composed of nebulous matter, the constituent parts of which are broken up and dispersed by the incessant action of the Sun's rays upon them, the lighter particles yielding more readily than the heavier ones under the impulse of the rays, thus proceeding to greater distance,

and forming the tails of the comet. The denser particles form the nebulosity about the head. This theory explains easily the curvature of the tails, and accounts for most of the cometary phenomena satisfactorily.

In his history of physical astronomy Grant remarks: "Another advantage of this hypothesis was that of referring the phenomenon to a true physical cause; for it can hardly be doubted, whatever be the mode of propagation of light, that the solar rays, if interrupted in their progress by a material substance, must communicate to it an impact of *some* degree of intensity. On the other hand it must be admitted that the cause assigned, although founded in nature, cannot, with any degree of probability, according to Kepler's view of it, be considered sufficient to produce the observed appendage of the comet. A material improvement of the hypothesis of that astronomer consists in introducing the solar heat as one of the exciting causes of the phenomenon."

Claude Comiers, a French writer of the middle of the 17th century, explains the tails of the comets upon this enlarged view by supposing the nebulosity of the comet so rarified under the influence of the Sun's heat, that it yields with facility to the impulse of the Sun's rays, and thus acquires a motion away from the Sun, forming the appendage known as the tails. By supposing the nebulosity sufficiently attenuated a rational theory could thus be developed, as it eventually was by Whiston, a contemporary of Newton.

Newton himself supposed the rays of the Sun, by their heat, to raise the temperature of the nebulous particles of the comet, which in their turn communicated a portion of the heat thus acquired to the contiguous particles of the ethereal fluid composing the solar atmosphere. As this increase of temperature, according to his view, would be accompanied by a corresponding diminution of density, he imagined the particles of the ether to ascend from the Sun, carrying along the more volatile portions of the comet, just as smoke is wafted upwards by currents in our atmosphere. Newton's theory was not well received, though it furnished a working hypothesis which was more or less used during the next century.

One hundred years ago a theory of electric repulsion was proposed by the German astronomer Olbers. It was afterwards given extended application by the illustrious Bessel and by Sir John Herschel, and has in later years been generally accepted by such authorities as Zöllner, Peirce and Huggins.

About fifteen years ago the Russian astronomer Bredichin devoted elaborate study to types of comet tails, and the repulsive forces by which their forms may be explained. Among the different types of tails recognized are:

1. Long, straight rays, formed of matter on which the Sun's repulsive force is from 12 to 15 times as great as the gravitational attraction, the matter, according to Bredichin, being most probably hydrogen gas.

2. Curved, plume-like tails, exhibited by many comets, the matter being repelled by a force 2.2 times that of gravity, and most probably composed of hydrocarbon gas. Donati's famous comet of 1858 combines both these types of tails.

3. Short stubby tails, violently curved, the repulsive force being on the average 0.3 that of gravity, and most probably composed of vapor of sodium, iron and other metallic substances.

The classification set forth by Bredichin has been accepted as sufficiently explaining most of the facts, but the nature of the repulsive forces has remained in doubt.

Of late years the attention of astronomers has been directed more and more to the changes taking place in the heads and tails of comets, which frequently are of surprising rapidity. By the aid of photography in the hands of such experts as Gill, Barnard, Hussey, and others it has been shown that the sudden changes often depicted by observers of comets and heretofore generally discredited as improbable, do really take place; and a satisfactory record of an important comet can now be obtained only by repeated photographs of long exposure taken at short intervals. These unbiased photographic records alone enable one to trace the development of tails and changes of internal structure, in such a way as to show the origin and direction of motion of the material driven from the Sun.

The year 1873 is likely to be memorable in future histories of the theory of comets; for in this year Professor James Clerk Maxwell, one of the most illustrious physicists of all time, published his great work on electricity and magnetism, in which he proposed his famous electro-magnetic theory of light, since confirmed by numerous physical researches. In advancing this theory he says that to fill the universe with a special kind of ether each time a new phenomenon is to be explained is unphilosophical, and then proceeds to show that the velocity of light and electricity is the same; he also shows on the strongest grounds of probability that the two phenomena, light and electricity, are different forms of energy depending on wave distor-

tion or stress of the luminiferous ether. According to Maxwell the different forms of energy depend mainly on the length, shape and form of the ethereal waves.

For some time it seems to have been almost overlooked that Maxwell's electro-magnetic theory of light required that light itself should exert a slight pressure on material bodies in the direction of its propagation. The distinguished Swedish chemist Arrhenius has recently explained in this way the repulsion of comets' tails, the solar corona, the zodiacal light, the gegenschein, and the aurora borealis. The impression made by Arrhenius' work conducted along the line of thought struck out by Maxwell is very decided, and we shall review it at considerable length.

For the benefit of the lay reader it should perhaps be remarked that the *Corona* is the term applied to the halo of light which surrounds the Sun when obscured by the Moon during a total eclipse. This beautiful light, of a delicate silvery appearance, comes from fine matter mainly in the solid state suspended near the Sun, and kept there by forces hitherto unknown. The matter of the corona is known to be thinner than that in the vacuum of the best air pump, and offers no sensible resistance to the motion of comets, which pass through it in their flight about the Sun, without suffering the least disturbance. In fact the unimpeded passage of comets through the corona is the criterion employed to show the excessive tenuity of the matter constituting it.

The *Zodiacal Light* may be seen on a clear evening as a faint luminescent cone with base on the western horizon and vertex extending upward from the Sun from 40 to 60 degrees. Its principal axis lies near the plane of the ecliptic. The light is supposed to be due to the reflection of sunlight from small particles, such as meteorites, or the waste matter of comets, revolving round the Sun in the plane where the planets move. This curious phenomenon has been known for a long time, having been first described by Kepler early in the 17th century; but accurate observations of it are of comparatively modern origin. They are most easily secured in tropical climates, where the duration of twilight is short, and the cone of the zodiacal light rises nearly perpendicular to the horizon. Humboldt noticed that this phenomenon was very conspicuous to an observer on the high plateaus of Peru, early in the 19th century; and a similar record was recently made by the writer while at the Lowell Observatory, on the elevated plains of the City of Mexico. Though best seen in the tropics this light may be recognized in almost any part of the

United States, especially during February and March when the ecliptic rises most nearly vertical to our western horizon. The dry climates of our southwestern territories are particularly favorable for viewing the zodiacal light, and some photographs of it have recently been taken there.

The *Gegenschein* is a very faint luminous area with a diameter from five to eight times that of the Moon covering the region of the sky exactly opposite the Sun. The cause of this faint luminescent phenomenon is not known, but is usually ascribed to the glow of particles in the shadow of the Earth, probably excited by some electric agency, either of terrestrial or solar origin.

The *Aurora Borealis* is due to electric discharges in the higher regions of the Earth's atmosphere. It is observed chiefly in northern latitudes, but is frequently seen in the United States. Some scientists claim that its location is nothing like so high as has been supposed, and is in fact very near the Earth, at the height of ordinary clouds.

By his mathematical investigations Maxwell showed that the propagation of a beam of light through the ether caused a slight pressure to be exerted on an exposed surface in the direction of the rays of light. This pressure is so small that it has required the most delicate of all modern experiments to detect it. So slight a pressure emanating from the center of the Sun could exert no sensible influence as against gravity, when the bodies are large, but in case of bodies of smaller and smaller size, the ratio between the mass of the body and its exposed surface decreases rapidly when minute dimensions are approached, so that for small spherical globules of the same density as water of one one-thousandth millimeter diameter, the light pressure is found to be equal to that of gravitation. This singular effect is analagous to the more familiar case of fine dust wafted by terrestrial winds. Thus it is found that very minute grains of sand, the finest particles of dust from the desert, are carried by winds high up into our atmosphere and deposited so slowly under the onrush of strong currents of air that they fall thousands of miles from where they started, and thus cover the beds of the ocean over the whole Earth; while the large grains of sand less effected by the forward movement of the atmosphere fall quickly to the ground, and are seldom deposited beyond the desert itself. The force of the wind has little effect on large grains of sand but is extremely powerful on those which approach the size of fine powder. So it is with the repulsion of particles due to the light waves emanating from the center of the Sun; this pressure has

little effect on bodies as large as small grains of sand, but repels powerfully much finer particles, such as those little microscopic pieces of carbon which float in flames of low combustion.

It may be noted that a millimeter is roughly the diameter of the average grain of sand used in making lime mortar for building purposes; such sand is found in creeks and rivers, as well as on the sea shore, and is perhaps as convenient a symbol as one can choose for illustrating those values to the lay reader. If a spherule have one one-thousandth of the diameter of a grain of sand, it will weigh only one one-billionth as much as the latter. Thus when the diameter becomes very small, the particles are almost wholly devoid of weight.

Now it is found by computation that under the repulsion of the Sun's light a particle one one-thousandth the diameter of an ordinary grain of sand would just float in space at whatever distance it might be placed relative to the Sun. If below this dimension (so long as the diameter is not less than a critical value) it would be repelled from the Sun, because the pressure of the light exceeds the attraction of gravitation. If larger than the dimensions above indicated, the force of gravity would predominate, and the body would slowly fall to the Sun, the velocity depending of course on the actual size of the body and its density. As the size of a spherule diminishes, the light pressure would diminish as the square of the diameter, while the weight would diminish as the cube of the diameter. In this way spherules of the density of water larger than one sixty-sixth millimeter would be more effected by the attraction of gravitation than by the repulsive force of the Sun's light. If, however, the diameters of these spherules decrease steadily, it is a curious fact recently brought to light by the profound researches of Professor Karl Schwartzschild of Göttingen, that after a diameter of one fourteen-thousandth millimeter has been attained, the attraction of gravitation again exceeds the pressure due to the Sun's light. This arises from the fact that spherules with diameters smaller than the wave-length of light are not much effected by the pressure which light waves exert. In this way very small spherules of matter would not be greatly repelled by the Sun. Thus matter in the molecular stage would not be strongly repelled by light, because the diameters of the molecules are much too small—smaller than one three-hundred-thirty thousandth millimeter. The spherules which could be repelled by the Sun are thus at least 23 diameters of the largest molecules, and cannot be gaseous matter in an elemental stage. It is held that they must in

fact be masses, or globules of matter containing about ten thousand molecules of the larger kind, or something like a million of the ordinary size. Now as the finest portions of matter, the electrons especially investigated by Professor J. J. Thomson, are as small as one one-thousandth of a hydrogen atom, it follows that the spherules repelled by the Sun's light may contain many millions of the finest particles into which matter may be subdivided. Such spherules would have to be more or less solid to be effected by the pressure due to the light. We reach the conclusion then that the tails of comets repelled by the light of the Sun are composed of small solid particles, of the same order of size as the particles of carbon which float in flames of low combustion.

In order to see these globules more distinctly in their true proportions, let us look at them through a magnifying glass. Suppose our eyes magnified all objects so that their diameters appeared one thousand times larger than they really are. Then, assuming the density to be equal to that of water, those particles which would just float about the Sun under the repulsion of its light would appear as large as ordinary grains of sand; those which the light would not repel, because of their minuteness, would be less than one-tenth the diameter of a grain of sand; while those which light would not repel, on account of their weight, would have a diameter fifteen times that of a grain of sand, or appear about the size of cherries. On the same scale the largest molecule would have a diameter of about one-three-hundredth that of a grain of sand, which is of course much too small to be seen by itself. In fact it would take from ten thousand to one million such specks to make a grain of sand and something like a billion such specks to make a mass the size of a cherry, which light would not repel on account of its weight. If, still using our magnifying glass, we look at the stream of matter driven out of the Sun by the repulsion of its light, we should probably find that rapidly moving current to be composed of particles varying in size from one-tenth the diametes of a grain of sand,—about like chalk dust,—to that of cherries or grapes. All the region about the Sun is bombarded by millions of these fine shot every second, so that the result is the maintenance of those beautiful streams of silvery light of exceedingly fine texture, constituting the corona, observed about the Sun during a total eclipse. The stream of matter forming the tails of comets is evidently of similar constitution. The zodiacal light is supposed to be sunlight reflected from such particles and

perhaps others of a larger size like the meteorites which strike our atmosphere.

Some discussion has recently arisen as to how the very fine, almost elemental particles of gas developed at the incandescent surface of the Sun or possibly in the heads of comets, could be repelled by light pressure when the diameters are smaller than the wave lengths of light, or rather how these particles could by accretion acquire the necessary diameter to be expelled by the motion of the light waves. It is held that the charged negative particles emitted are excellent nuclei for the condensation of small drops, and these spherules, not the elemental corpuscles themselves, are driven off under the pressure of the Sun's light. The particles repelled are thus supposed to be liquid or solid masses of measurable diameter. Dr. Halm of the Royal Observatory, Edinburgh, who has given much study to this and kindred solar phenomena, claims that Zöllner's theory of comets, according to which the Sun acts as an electrified body, is after all preferable to that put forth by Arrhenius and ably supported by Professor Cox of Montreal. It is known that a hot surface such as that presented by the Sun emits a continuous stream of electrons. These are the most infinitesimal corpuscles known to exist, and in mass do not exceed one one-thousandth of a hydrogen atom. It is held by some who have studied the electronic theory of electricity that the vibrations of the ether are excited not by the atoms themselves but only by the electrons. The electrons alone, according to this theory, excite vibrations in the ether, and produce radiation; and an atom of the ordinary type is conceived to be a kind of planet accompanied by smaller satellites which are the little electrons. These electrons, though a kind of satellite to an ordinary atom, may exist separately from the atom, in which case they are particles of negative electricity; and a current of electricity is looked upon as made up of a stream of these infinitesimal corpuscles, the smallest known existing things. An atom appropriately supplied with electrons is electrically neutral, but with the loss of some of the electrons becomes a positive atomic ion; with a superfluity of electrons, it becomes a negative ion.

The fact that light is frequently emitted without heat is explained by the vibration of the electrons associated with the atoms, and molecules, the vibrations of which alone determine temperature. The light emitted by the cold nebulæ of space admits of easy explanation by this hypothesis, according to which the electrons of particular atoms and molecules in the

nebulæ are agitated rather than the atoms or molecules themselves, and the waves from the vibrating electrons determine the light which we receive, but give no indication of the temperature of the nebulous mass.

According to Dr. Halm's view of Zöllner's theory of comets, the space about our Sun in all directions is to be considered as a negatively charged electric field acting on ionized cometary matter, which enters it from the regions of the fixed stars. Assuming the propagation of free negative electrons from the Sun into space, with the enormous velocities they are known to have, which according to Weichert are from one-fifth to one-third that of light, he would explain the tails of comets in close accord with the original views of Olbers, Zöllner and Bredichin. These electrons uniting with the atoms of certain chemical elements in the comets are of course repelled by the Sun, so that the phenomena presented by the tails of comets find a plausible explanation on the electronic theory. In this way Dr. Halm explains the existence of only three types of comet tails corresponding to the chemical elements assumed by Bredichin, rather than an unlimited number of types, such as might be expected by the theory of Arrhenius founded on Maxwell's pressure of light.

It is too early to judge the claims of these two rival theories, but it is evident that the truth lies somewhere between them, and that at last we are approaching the correct explanation of the phenomena of comets' tails. The spectacles offered by comets are the most impressive and artistically the most beautiful of all the celestial phenomena presented by nature to the contemplation of the inhabitants of the terrestrial globe; and it is a curious fact that these extraordinary appearances now observed carefully for many centuries have proved to be the most mysterious of all the problems requiring the attention of the philosopher.

In connection with the repulsion due to the pressure of the light, and its probable verification in the tails of comets, it should be pointed out that proof of an experimental character has recently been supplied, showing by laboratory experiments that a beam of light exerts actual pressure upon a surface on which it impinges. In fact three different experimenters independently reached such a result almost simultaneously, Professors E. F. Nichols, and G. F. Hull, two American investigators of great skill working conjointly at Dartmouth College, and a Russian physicist, Peter Lebedow, of Moscow. These investigators have thus confirmed in the laboratory the early mathematical conclu-

sions of Maxwell, and given the theory of light repulsion an experimental basis, which makes it a permanent part of physical science.

There have been few more important researches in recent years than this one, and none is surer of an appropriate place in history, or more likely to be found useful and suggestive in the future progress of discovery. Thus a definite and important step has been accomplished in the theory of light. As long as the emission theory of Newton, that light is due to small corpuscles emitted from the radiating body, held among men of science, it was natural to think that the bombardment of those corpuscles might effect a repulsion of the tails of comets; but when the wave theory of light was established by Fresnel about 1840, there was no longer any obvious basis for the supposed repulsion of matter from the Sun. It thus required the master mind of Maxwell to prove mathematically that light waves also exert a pressure, and finally experimental proofs of his conclusions to render the evidence decisive and final.

If we inquire what happens to the tails of comets, under solar repulsion, whether it be due to light pressure, or to the discharge of electrons which oppositely charge the particles of comets, or to both of these causes combined, it will be evident that some of the matter repelled with great velocity, is driven away never to return to our system. There is thus a loss of matter due to the repulsive force of the Sun; and if sufficient cometic matter were falling into the solar system the Sun might appear surrounded with faint nebulosity when viewed from a neighboring fixed star. Accordingly when we look out into space with a powerful telescope and see the nebulosity, or faint hazy light about some of the stars, what are we to conclude? The answer should probably be this: Either the nebulosity is falling into the stars to form them, as supposed in the nebular hypothesis, or it is being driven out of them by repulsive forces, due either to the pressure arising from the light of the stars, or to the electrons emitted by their flaming globes, exciting repulsion and perhaps luminesence in cold particles circulating around them.

According to the nebular hypothesis the nebulosity observed around the stars is falling into them, and is in fact gaseous matter at a high temperature. Yet it is known that such attenuated matter infinitely expanded must be cold, and hence how can its luminosity be accounted for on the old theory? We may answer the question in the negative with entire confidence, and *assert that whatever be the cause of the light of the nebulae it is not*

heat, but electric discharges or some luminescent effect depending on the discharge of electrons at excessively low temperatures; for since the nebulæ are known to be at the temperature of space, excessively near the absolute zero, 273 degrees below freezing on the centigrade scale, no other theory seems to account for the phenomenon with any degree of probability. Is it not therefore natural to suppose that perhaps all the stars are fed by the inward flow of dark cometary matter at low temperature, and the parts of this material repelled by light and by electronic excitation takes the form of the nebulous wisps observed about the stars in our telescopes? Of late it has been becoming more and more probable that our popularly accepted ideas about the nebulæ are quite antiquated if not positively erroneous. For several years the impression has been growing on the minds of men of science that perhaps nebulosity may be expelled from the stars, and does not really afford the basis out of which they are constituted. I was myself led to this idea in 1898-99 while lecturing before the Lowell Institute, Boston, and in January, 1899, expressed such views in a public address at Wellesley College.

If the nebulæ really form the stars it seems remarkable that their spectra should exhibit such few lines, chiefly those of hydrogen and *nebulium*, whatever that may be. And if the stars are formed of nebulæ, why do not sodium, iron and other metallic lines appear in the spectra of nebulæ? We may even admit that only the centers of bright nebulæ have any sensible temperature, and yet on general principles find it exceedingly difficult to understand why *some* of the nebulæ should not exhibit metallic lines. These huge masses rarer than the vacuum of any air pump, are known to be practically at the absolute zero; possibly the low temperature of space may account for the presence of spectra of such elements as hydrogen and nebulum, which are volatile, and glow under electric discharge at low temperature. In many cases the nebulæ have such irregular wisp-like forms, that it is of course impossible to think of them as an aggregation of gross matter in equilibrium under the simple attraction of gravitation.

To the unprejudiced observer they obviously appear as the products of explosive forces rather than masses of gas condensing into stars. This indication of repulsive forces becomes especially conspicuous in the outskirts of the Orion Nebula, and those wispy nebulosities so beautifully photographed in the constellation Cygnus. Taking the heavens as a whole the nebulæ as a class are so irregular in figure as to produce the impression that they are patched up out of matter driven out of the stars, rather

than matter forming stars by gravitational condensation. The spiral nebulæ, which appear to be quite numerous, may represen- an unequal contest between attractive and repulsive forces combined with rotatory motion.

The diffused nebulæ like the Ring Nebula in Lyra, and the Trit fid Nebula in Sagittarius are evidently large masses of nebulosity without violent or decided movement of their parts. It seems as if the wispy nebulosity so abundantly scattered over the constellation Cygnus might be the casual aggregation or juxtaposition against the sky of wisps of fine matter driven from numerous centers in the universe by repulsive forces. The general appearance is that of smoke wafted about in our atmosphere by unequal currents. It may be noticed that the phenomenon of the dark hole about the Trapezium in the Orion Nebula, hitherto accounted for on the assumption that the stars have "eaten out the nebulosity in their immediate neighborhood," may be equally well explained by supposing such matter expelled by the repulsive force of the stars forming the Trapezium. The surroundings of the stars from this cause would, under certain conditions, appear quite dark. A like explanation may be offered of the appearances of numerous other nebulæ many of which have a "stringy" aspect, as if rent by currents in a surrounding fluid; but at present it is not thought best to go into too much detail. It is sufficient to state that up to this time there is no absolute proof that nebulosity forms the stars.

It seems certain that the light and heat of the stars is due to the gravitational condensation of ordinary matter, probably of a non-luminous character, while the wisps about stars such as the group of the Pleiades may be fine matter driven out of the cluster by repulsive forces issuing from the several stars. In fact a general study of the figures of the nebulæ goes far to suggest that nebulosity has very little to do with the formation of stars, but is a material composed of two or more elements expelled from various stars, and gathered together here and there in space, and shining by a feeble light, akin to electric luminescence. This of course does not alter the fundamental views that the matter forming the stars was originally dark, but it does suggest that nebulosity, with its faintly-lined spectrum, has little connection with true stellar evolution.

Hitherto it has always been assumed that the stars are the usual products of condensed nebulosity; perhaps in future it will be advisable to inquire seriously whether such an assumption is justified by the appearance of the material universe. Are not the

stars really formed from dark unseen matter, and the nebulosity expelled from the stars as they develop, either by the pressure of their light, or by electric forces excited by the discharge of electrons?

So far as one can see almost all the evidence is favorable to an affirmative answer to this proposition; and yet such a view at first sight seems startling. In studying the question we should remember that only about one hundred and thirty thousand nebulæ would be found in the heavens, if the whole sky were carefully photographed by such an instrument as the Crossley reflector, so effectively used by Keeler at the Lick Observatory in the exploration of new nebulæ. There are at least one hundred million stars visible in our most powerful telescopes.

It thus appears that using the most powerful appliances of our times the stars outnumber the nebulæ in the ratio of nearly a thousand to one. If the stars form from nebulæ, why this extraordinary contrast in the relative numbers of the two classes of objects? It may be said that as all nebulæ are cold, probably many of them are dark and wholly unseen, as was pointed out by the writer some four years ago. It might also be held that small faint nebulæ corresponding to small stars, would be seen with difficulty, because their light would thus make a more distinct impression upon the retina or upon the photographic plate. But it now seems more probable that most if not all the matter which forms the stars is originally dark, and the shining films called nebulosity are that part of the matter most effected by repulsive forces, driven out of the various stellar centers, and here and there aggregated into cold masses of enormous size but excessive tenuity and shining with a feeble electric glow. The repulsion due to the powerful light or electronic effect of a star like the Sun might effect all chemical elements alike; but Arrhenius points out that at the borders of the nebulæ electric discharges would take place, and cause a glow of only the lighter and more volatile elements, chiefly hydrogen and *nebulium*, which are easily rendered luminous at low temperatures.

The existence of explosive forces of enormous power in the development of the universe has been suggested by several previous writers. Those who view the tree-like structure often exhibited by the Milky Way and the radiating aspect of certain clusters, see in the arrangement suggestions of repulsive forces too stupendous for comparison with any forces encountered in the solar system. The isolated arrangement of the two Magellanic clouds, and the bifurcation of the Milky Way, and the stream-like ap-

pearance presented by many groups among the millions of stars composing these imposing masses of star dust, may be due, however, not so much to the action of explosive forces, as to primative impulses given to portions of the Galaxy, or slowly acquired by them under the gravitation of the whole system in the course of immeasurable ages. The clustering power at work in the Milky Way noticed by the elder Herschel as giving that stupendous arch the aspect of breaking up or curdling into a series of clusters rather than the appearance of a uniform band of milky light, should probably be ascribed to the secular effects of universal gravitation, operating on systems of gigantic extent. Then, too, it must be remembered that some approach to a stream-like drift, a tree-form, or radiation from a center, may frequently be ascribed to simple chance, where the stars are so thick as they are in some portions of the Milky Way.

The existence of true repulsive forces is, I think, much more to be inferred from the appearances of the nebulæ and the more compact clusters than from masses of stars scattered over wide areas.

In the case of those nebulæ which cover an immense extent, such as the famous "spider-web" nebula in Cygnus, we may see at once the effect of repulsive forces superposed upon a secular drift of the nebulosity. At present it is of course impossible to separate the two effects.

It is not claimed that the views here set forth are fully established by the results of scientific research; they are simply suggestions, which may be of use in the future progress of science, and must when tested stand or fall on their merits. But that repulsive forces play a larger part in the universe than has been generally supposed the writer is daily more and more convinced. The important point to bear in mind in this connection is that light is shown to exert a repulsive force, and this is known to be effective in repelling globules of matter of a certain size. On another theory electrons are also emitted by all hot bodies like the Sun and stars, and these minute corpuscles traveling with velocities approaching that of light, are at once capable of electrifying neutral atoms or molecules, so that they are repelled by very powerful electric forces. These causes are adequate to account for all the repulsion of matter observed in the solar system and among the fixed stars.

In conclusion we should remember that gravitation condenses the matter forming the stars from a state of infinite diffusion and chaos; this condensation produces heat and light and the radia-

tion of electrons, and the waves of light and electric forces emanating from such centers repel all matter of a certain fineness or of a certain chemical constitution so powerfully as to diffuse it again to the bounds of the universe. There is thus in nature a partial counteraction of the condensing and aggregating tendency of universal gravitation. *Some of the matter is again spread over the universe by the indirect effects of the same agency which caused the condensation.* How far this process of redistribution goes, and what proportion of all the matter now falling into the stars for the maintenance of their radiation, is thus effected, cannot at present be determined. But probably only a small fraction of all the matter drawn in is ever expelled, so that condensation continues, with slightly retarded rate.

It is interesting to notice, however, that if this expulsion of matter should by any possibility of future discovery prove to be equal to that drawn in by the attractive force of gravitation, it would be conceivable for the universe in its present state to last forever, a thing heretofore considered impossible. This perpetuity of the universe, to be sure, does not at present seem very probable, but we know as yet too little to say that it is wholly impossible. There may be some laws of nature of a far-reaching character heretofore unknown and wholly unsuspected yet to be discovered. And these may show that repulsive forces in nature called into play by gravitation itself aid in redistributing what gravitation has accumulated by its condensing power. At any rate in the future study of the heavens repulsive forces must be considered before forming any final estimate of the destiny of the physical universe.

WASHINGTON, D. C., April 2, 1902.

ON THE PERFORMANCE OF A 6 1-4 INCH BINOCULAR TELESCOPE.

D. W. EDGECOMB.

FOR POPULAR ASTRNOMY.

Some time ago, (POPULAR ASTRONOMY No. 18, April 1895), the writer gave a brief account of a binocular telescope with object glasses of 6¼ inches aperture which had just been made by Alvan Clark & Sons, and promised to report upon its performance. I believe that no twin telescope of this size, in which the utmost optical perfection was aimed at, has hitherto been made, and I have applied it to the observation of some of the most minute

and difficult objects with an interest that has grown with the opportunities for use afforded by this most disappointing climate. For various reasons I have not had so many opportunities for trial and use as I hoped for; the delay in reporting has not been caused by want of success in performance. My previous belief in the advantages of binocular vision with the largest instruments to which it can be practically applied, for celestial as well as terrestial use, has been fully confirmed by this telescope, and the pleasure afforded by its use has far exceeded that which I have derived from observations with any other instrument which I have possessed.

It is not necessary to enlarge upon the desirability of employing both eyes whenever possible, in telescopic vision; every one recognizes the advantage in small glasses; I think that almost any experienced observer with single instruments would find it difficult to suppress an exclamation of surprise and pleasure at the first view of a terrestrial picture or of the Moon or planets with this binocular under favorable conditions. The reasons are: the object observed seems larger and nearer, the atmospheric tremors are reduced so that definition is better and faint detail is more certain, while vision is easier and less fatiguing. The very large field in the case of terrestrial objects which, it is to be remembered, are presented erect and natural by the prismatic eyepieces, gives a charm which cannot be described.

That we should ordinarily see objects better with both eyes than with one, and be able to form a much better estimate of their nature, is of course understood and expected; our whole visual experience makes it so; that an object seen in a telescope under considerable power should seem to be both larger and nearer when viewed with both eyes than with one, with the same power, is not so easily explained. The fact however, to the observer is not only evident but obtrusive, the more so the greater the power of the instrument. How much larger the object appears it is difficult to estimate. Dr. Kitchener tells us that for want of glass good enough in his day to make larger objectives, binoculars were made, and there were differences among observers in their estimates of the gain by their use. They all agreed that objects seemed larger and nearer; many thought they seemed one-third greater. The doctor regretted that the loss of one eye prevented him from giving his readers the benefit of his experience. My own estimate agrees with that of the early observers. When looking at Jupiter or Saturn, for instance, if after using one eye, I open the other, the combined image at

once increases notably in brightness and in size. Not only that, but detail gains in outline and steadiness. One is reminded of the enlarged full Moon at the horizon: we know it seems larger, nor can the clear conviction that the optical angle is actually somewhat less, overcome the seeming; and undoubtedly if the the atmosphere would permit the distinctness in that position which the Moon has when near the zenith, the detail of her surface would appear with a plainness corresponding with the apparent increase in size. In the case of the binocular the seeming enlargement is even more persistent. Taking terrestrial objects, looking first with one eye and then with both, the picture, covering a field twice the size obtainable with any four glassed eye-piece of the same power, at once brightens, approaches and becomes stereoscopic.

An unexpected effect of the binocular is increased steadiness; with the same power the image becomes less tremulous or wavy in outline when after looking with one eye, both are used. For this a reason can be given. The atmosphere is never still. We read the accounts by Mr. Pickering and Mr. Lowell of the conditions ot the actual physical millenium at Arequipa and Flagstaff about as we read the poet's prophetic dream of the coming moral millenium; but with observers generally all over the world, the atmosphere trembles, wavers and boils, never entirely ceasing, forming

"That Isis veil no hand may rend."

In the telescope the image is seen alternately clear and blurred; we call it good seeing in proportion as the intervals of clearness exceed the opposite. Now with two telescopes and an eye applied to each, the intervals of clearness alternate, we see steadily first with one and then with the other, and a much more nearly continuously sharp image results. This combines with the seeming larger image in securing detail. If a test object is tried, as letters, figures or engraved lines at the extreme limit of vision, with one eye and then both, the effect is plain; the image changes to greater steadiness and more words or figures can be made out. The same conditions produce an apparent enlargement and more perfect outline of minute discs, notably the satellites of Jupiter and the minute craters of the Moon. It is interesting to note how suddenly these latter stop winking when one gazes at them with both his own eyes open, each with its telescope. The practical result of this quality of the binocular appears to be that it gives the effect of an enlarged aperture without a corresponding

increase in tremor. Apparently, indeed, with a portion of the light, a portion of the tremor is also absorbed by the prisms.

Of course the work must be perfect, this is easier now than formerly, but still it is a matter not to be obtained at will and anywhere, nor cheaply. The pair of object glasses, in the instrument under consideration, measure 6 5/16 inches clear aperture, and in material and figure are not to be surpassed. After long trial, I cannot conceive how a better objective can be made, unless, without impairing figure or purity, the small remnant of color in these could be eliminated. And the absolute similarity is notable, with a focal length of 94 inches there is not a difference exceeding a hundredth of an inch. It is beyond detection. It will be understood of course, that this perfect similarity is not absolutely necessary to the practical perfection of the instrument but the skill that produced it cannot be too greatly admired. Mr. Clark took great pride in this accomplishment, and told me more than once that they were fully equal to any object glass they had ever made, and that the skill required to produce them thus absolutely alike was equal to that ever given to any work of theirs. These considerations are interesting because the performance of the instrument results from this work; and should the performance be imperfect it would be useless to try further. I recall here a characteristic remark of the elder Clark, long ago, when I was wishing at one of my visits to him, to have a binocular made. He feared I would not be gratified very soon, as telescope makers, he said, do not like the idea of having to make two instruments to get one; there was trouble enough in making one and having it perfect. I have compared these object glasses ever since they were made, with silvered reflectors; in light they are equal to an 8½-inch mirror at its best, and in definition they approach as closely to the mirror of that size as a refractor can be made to do.

Without the prismatic eyepieces there could be no binocular of any size useful in astronomy; and it is here that skill and perfect material are quite as necessary as in the objectives. While constructing the instrument we waited some time to receive from the French maker, upon Mr. Clark's order, the clearest piece of glass he could produce for the prisms. They are about 2⅞ inches long and 1 5/16 inches thick; the rays from the object glasses traverse about 5½ inches of glass. I have never been able to find any method of ascertaining the absorption. It must be an eye estimate at best. It is not so much as one would think. It may be twenty per cent. After long practice I am satisfied that I can see as

faint objects with both eyes and the prisms as I can with one eye without them. The gain by using both eyes seems to balance the loss of light. But I see detail better, seeing is less tiresome and the beauty of all objects is greatly enhanced. I cannot undertake to say to what perfection of flatness—what minute fraction of a wave length—the surfaces of these prisms are worked by Mr. Lundine, the present head of the Clark establishment. The whole work, I presume it is proper for me to now say, of objectives and prisms, was his and the skill was his. I have repeatedly compared the image of a near-by well-illuminated object with the prismatics and without them, with powers up to a thousand, and the definition seemed equal, with loss only of light by the prisms. Absorption does no harm with certain objects; in other cases it is a benefit rather than otherwise; just as a larger aperture and less proportional light in the reflector is an advantage and a desirable quality instead of being an objection as is sometimes urged. Stars like Antares, Delta Cygni and Zeta Herculis are nicely shown by the binocular; the absorption clears the disc of the larger star while the smaller one can well bear the proportional loss of light. So these and other close and not too unequal doubles are separated with less power than is required for the single telescope. With faint objects the instrument rather exceeds one's expectations; probably my practice with it has enabled me to see more than at first. The 12″ companion to Beta Aquilæ is nearly always plain enough, and so is the companion to Alpha^2 Capricorni. I have more than once seen this star double; no one I venture to say has ever seen it with less aperture than this. I have once or twice seen Clark's 10 second companion to Gamma Lyræ. On a December evening in 1900 I was looking at the great nebula, and the fifth and sixth stars were so bright, showing prominently the red color of the latter, that I brought the group 42 Orionis into the field. After a moment I saw steadily the faint companion to each of the stars. Then I turned to Tau Orionis; the preceding companion was so plainly double that I could see the difference in size of the components. Finally the Mitchell companion to Rigel was steadily seen. These are quite enough to convince the reader that the binocular is fully equal to any single instrument of its aperture with the best astronomical eyepiece possible. I think that an aperture of 7 or 8 inches is generally considered necessary to show Mitchel's Rigel star. And its visibility in the prismatic eyepieces illustrate the absence of glare and the unimportant loss of light. Bright clusters, say those of Perseus and Hercules, the great nebulæ and

the Milky Way in Cygnus or Sagittarius, are strikingly beautiful with both eyes and a moderate power. In these latter regions and in the *Via* generally, the curves and rows, the loops and lace-like structure seize upon the attention at the first glance.

It will be understood, of course, that the prisms tend to produce opposite effects with regard to glare or diffused light. In the case of a brilliant object, absorption would tend to reduce it while imperfections in the prism surfaces would produce it. When we consider that the light from the object glasses passes and is reflected by these surfaces eight times before reaching the eye, the result in the above tests seems very remarkable. In the beautiful Porro prismatic field glasses, the highest power applied is about 20 to the inch; these prisms, so many times larger, permit the use of five times that power.

It is, however, the Moon and planets that offer the best field for showing the advantages of binocular vision, under these perfect optical conditions. The reduction of glare, the greater steadiness, and as compared with the single instrument, the seeming greater nearness and larger images under the same power, affect the observer so that he cannot avoid the impression that he sees these objects better than ever before. Saturn is most picturesquely moulded. Those *ropes of sand*, the rings, as easily deceive both eyes as one, and they seem even more solid than ever. I have seen with this instrument every feature that I have seen with any larger one, the planet being unique, I believe in this: that everything hitherto certainly seen upon rings or ball with the largest telescopes and anywhere, is within reach of perfect ones of moderate size; a satisfaction certainly, to amateurs. With all its garniture, however, Saturn does not in this as in the single telescope, so far surpass Jupiter in interest. The latter in the binocular field is no longer the figured disc of the ordinary instrument, and as represented in all drawings hitherto, but a floating globe. I have endeavored to represent him as such, and to show the beautiful perspective of the billowy masses of the belts. The spherical aspect is readily explained; the moulding is always there but it requires both eyes to see it. Just as the Moon, a disc to the naked eye, becomes a globe in the field of the small telescope. Absorption aids much in the moulding. I have shown it to observers under favorable atmospheric conditions, who thought it more impressive than Saturn; majestic, portly and cloud-laden. And nearly every one over-estimates the power, guessing 200 when 150 is being used; just as we under-estimate the power of the single instrument until we have learned. The

whole system, thus seen, of Giant Globe and his satellites, seems to be floating almost within the limits of the terrestrial atmosphere.

Upon the Moon the stereoscopic effect is striking. I can offer no explanation, unless it is because we always expect this effect when looking with both eyes at an object of light and shade. The minute craters, like those in such countless numbers about Copernicus, about Bullialdus and about Theophilus, appear to me as they do in a telescope of somewhat larger aperture. I have wondered often why it is that the pictures of these craters representing them as shown in large telescopes, say everybody's Copernicus except Nasmyth's, Neison's Theophilus and Smidts's Bullialdus, give no hint of these craters, the most interesting and impressive feature of these objects, which are hardly worth looking at with any telescope that will not show them. I do not know how to try to give the readers an idea of the very interesting aspect of the lunar scenery, seen with powers of say 250 or 300 in the binocular. I have found it interesting to adopt eye pieces of the largest field, free from stops, so as to intimate the conditions and appearance of natural vision; and with them one is at once greatly impressed by the nearness of the surface, the large extent of which taken in by the eyes makes it seem closer than is expected from the power used, while the perfect definition of the portion directly under the eyes with its innumerable craters, all produce the impression that we have been actually carried into close and almost startling proximity of the old familiar scene of desolation and ruin.

If my account is accepted it would appear that the application of the principle to instruments up to this size is practicable and useful. I think that with the perfect prisms now obtainable it might be extended to 8 inches aperture. Of course this must be taken only for that for which it is intended,—an account of an instrument equally adapted for Earth and Sky, unapproached for the former, and as regards the latter, capable of showing any object which a single instrument of equal size will show in a manner charming to the observer, and as I believe enabling him to get a more correct idea of the nature of objects just discernible at the limit of vision. It is for seeing, not measurement. And for this purpose its qualities adapt it more especially to this and all portions of the world where observers, especially amateurs, live and where the air is never still. Since those remarkable discoveries upon Mars which mark the present as the most interesting and important epoch since the invention of the telescope, I have en-

deavored, in common I have no doubt with many others, to learn by more careful study of conditions and the most attentive gazing, why one cannot see these objects with perfect instruments, even for a single instant, and I have become convinced that it is true as above stated, that the air in this region is never still. Always at the very best moments, when definition, say of the Moon or planets, is the sharpest we ever get, there remains a fine waving tremor which is enough to cover and hide the delicate markings which one feels may well be there and which the telescope might otherwise reveal. It is this last final enveloping veil of motion which dissolves in stillness at Arequipa and Flagstaff. Never for an instant is it absent here. This limits available power and this again limits useful aperture. And in this regard the question of large and small telescopes is worth a certain consideration. We may agree in the general statement of our best observers that one can always see with a large telescope whatever a smaller one will show, and see it better. Of small stars and all faint isolated objects this is quite true; but is it always true of surface detail upon the Moon and planets? I have some doubt in ordinary localities. For these objects the best vision results from a proper balance of light and power. Away from the favored spots it may be safely said that no planetary discoveries will ever be made hereafter with any aperture, except of changes, and changes will almost certainly be as quickly caught with moderate as with large apertures. Perfect optical quality is essential. So for this purpose, studying the Moon and planets and watching for new phenomena, like the bright spot upon Saturn in 1876, or those associated with *Linne* and *Messier*, large instruments have very doubtful advantage at ordinary stations over small ones: and in this view, the binocular is desirable, if I am correct in the belief that the natural mode of vision it affords enables one to more correctly estimate the nature of objects just discernible at the limit of vision. The general observer, it may be summed up, can never expect to make new discoveries of detail which will add to our knowledge of the physical condition of the planets; the scrutiny they have received and the results obtained, say in Peru and Arizona, preclude this, and preserve such further discoveries for these favored spots; his best course, promising most of pleasure, instruction and usefulness, will be to provide himself with means for seeing their surfaces the very best our conditions allow, and wait for new phenomena; and these may even tell us more of those physical conditions than the detection of more minute permanent detail.

The limitations and defects of this form of instrument will suggest themselves to the reader. There are ghosts of bright objects in the field produced by reflections from the prism surfaces. These cease to be troublesome after a little experience. The power which can be used is limited by the difficulty of keeping the two images together; with anything much above 300 considerable care is needed; and adjusting devices generally must be brought into use for each pair of eyepieces. My practice enables me to use 400 and sometimes more with very satisfactory results upon the Moon and planets. At first and for one without practice the two images will not always coalesce rapidly when more than 250 is used. The practice required is in holding the head steadily in proper position, which it is evident is much more difficult when considerable power is used than with the ordinary telescope. Any possible mechanical system would perhaps be too unstable in so large an instrument, to permit the use of the highest powers such objectives would bear when used singly. The least movement of air striking one of the tubes causes a change of shape, and in alignment or parallelism, and this separates the visual images. As has been shown, however, the powers which are really practicable are about all that one desires or finds useful in ordinary localities. Either instrument can of course be used by itself at any time for any purpose. To mount the binocular equatorially would involve some extra cost; the double tube would need to revolve within the sleeve carried by the cradle bar.

Any form of eyepiece can be used with the prisms. Those giving the largest field produce the best effect. Objects in the center of the field are free from color. The prisms are strictly no part of the eyepieces although I have spoken of them as such. They form an intervening system, bringing the rays to within the proper distance for the use of both eyes, and erecting the images formed by the object glasses.

LIQUEFACTION OF GASES AND LOW TEMPERATURES.

[CONTINUED FROM PAGE 477.]

LIQUEFACTION OF GASES AND CONTINUITY OF STATE.

In these speculations, however, chemists were dealing theoretically with temperatures to which they could not make any but the most distant experimental approach. Cullen, the teacher of Black, had indeed shown how to lower temperature by the evap-

oration of volatile bodies, such as ether, by the aid of the air-pump, and the later experiments of Leslie and Wollaston extended the same principle. Davy and Faraday made the most of the means at command in liquefying the more condensable gases, while at the same time Davy pointed out that they in turn might be utilized to procure greater cold by their rapid reconversion into the aëriform state. Still the chemist was sorely hampered by the want of some powerful and accessible agent for the production of temperatures much lower than had ever been attained. That want was supplied by Thilorier, who in 1835 produced liquid carbonic acid in large quantities, and further made the fortunate discovery that the liquid could be frozen into a snow by its own evaporation. Faraday was prompt to take advantage of this new and potent agent. Under exhaustion he lowered its boiling point from *minus* 78° C. to *minus* 110° C., and by combining this low temperature with pressure all the gases were liquefied by the year 1844, with the exception of the three elementary gases—hydrogen, nitrogen, and oxygen, and three compound gases—carbonic oxide, marsh gas, and nitric oxide; Andrews some twenty-five years after the work of Faraday attempted to induce change of state in the uncondensed gases by using much higher pressures than Faraday employed. Combining the temperature of a solid carbonic acid bath with pressures of 300 atmospheres, Andrews found that none of these gases exhibited any appearance of liquefaction in such high states of condensation; but so far as change of volume by high compression went, Andrews confirmed the earlier work of Natterer by showing that the gases become proportionately less compressible with growing pressure. While such investigations were proceeding, Regnault and Magnus had completed their refined investigations on the laws of Boyle and Gay-Lussac. A very important series of experiments was made by Joule and Kelvin "On the Thermal Effects of Fluids in Motion" about 1862, in which the thermometrical effects of passing gases under compression through porous plugs furnished important data for the study of the mutual action of the gas molecules. No one, however, had attempted to make a complete study of a liquefiable gas throughout wide ranges of temperature. This was accomplished by Andrews in 1869, and his Bakerian lecture "On the Continuity of the Gaseous and Liquid States of Matter" will always be regarded as an epoch-making investigation. During the course of this research Andrews observed that liquid carbonic acid raised to a temperature of 31° C. lost the sharp concave sur-

face of demarcation between the liquid and the gas, the space being now occupied by a homogeneous fluid which exhibited, when the pressure was suddenly diminished or the temperature slightly lowered, a peculiar appearance of moving or flickering striæ, due to great local alterations of density. At temperatures above 31° C. the separation into two distinct kinds of matter could not be effected even when the pressure reached 400 atmospheres. This limiting temperature of the change of state from gas to liquid Andrews called the critical temperature. He showed that this temperature is constant, and differs with each substance, and that it is always associated with a definite pressure peculiar to each body. Thus the two constants, critical temperature and pressure, which have been of the greatest importance in subsequent investigations, came to be defined, and a complete experimental proof was given that "the gaseous and liquid states are only two distinct stages of the same condition of matter and are capable of passing into one another by a process of continuous change."

In 1873 an essay "On the Continuity of the Gaseous and Liquid State," full of new and suggestive ideas, was published by van der Waals, who recognizing the value of Clausius' new conception of the Virial in Dynamics, for a long-continued series of motions, either oscillatory or changing exceedingly slowly with time, applied it to the consideration of the molecular movements of the particles of the gaseous substance, and after much refined investigation, and the fullest experimental calculation available at the time, devised his well-known equation of continuity. Its paramount merit is that it is based entirely on a mechanical foundation, and is in no sense empiric; we may therefore look upon it as having a secure foundation in fact, but as being capable of extension and improvement. James Thomson, realizing that the straight-line breach of continuous curvature in the Andrews isothermals was untenable to the physical mind, propounded his emendation of the Andrews curves—namely, that they were continuous and of S form. We also owe to James Thomson the conception and execution of a three-dimensional model of Andrews' results, which has been of the greatest service in exhibiting the three variables by means of a specific surface afterwards greatly extended and developed by Professor Willard Gibbs. The suggestive work of James Thomson undoubtedly was a valuable aid to van der Waals, for as soon as he reached the point where his equation had to show the continuity of the two states this was the first difficulty he had to encounter, and

he succeeded in giving the explanation. He also gave a satisfactory reason for the existence of a minimum value of the product of volume and pressure in the Regnault isothermals. His isothermals, with James Thomson's completion of them, were now shown to be the results of the laws of dynamics. Andrews applied the new equation to the consideration of the coefficients of expansion with temperature and of pressure with temperature showing that although they were nearly equal, nevertheless they were almost independent quantities. His investigation of the capillarity constant was masterly, and he added further to our knowledge of the magnitudes of the molecules of gases and of their mean free paths. Following up the experiments of Joule and Kelvin, he showed how their cooling coefficients could be deduced and proved that they vanished at a temperature in each case which is a constant multiple of the specific critical temperature. The equation of continuity developed by van der Waals involved the use of three constants instead of one, as in the old law of Boyle and Charles, the latter being only utilized to express the relation of temperature, pressure, and volume, when the gas is far removed from its point of liquefaction. Of the two new constants one represents the molecular pressure arising from the attraction between the molecules, the other four times the volume of the molecules. Given these constants of a gas, van der Waals showed that his equation not only fitted into the general characters of the isothermals, but also gave the values of the critical temperature, the critical pressure and the critical volume. In the case of carbonic acid the theoretical results were found to be in remarkable agreement with the experimental values of Andrews. This gave chemists the means of ascertaining the critical constants, provided sufficiently accurate data derived from the study of a few properly distributed isothermals of the gaseous substance were available. Such important data came into the possession of chemists when Amagat published his valuable paper on "The Isothermals of Hydrogen, Nitrogen, Oxygen, Ethylene, Etc.," in the year 1880. It now became possible to calculate the critical data with comparative accuracy for the so-called permanent gases oxygen and nitrogen, and this was done by Sarrau in 1882. In the meantime a great impulse had been given to a further attack upon the so-called permanent gases by the suggestive experiments made by Pictet and Cailletet. The static liquefaction of oxygen was effected by Wroblewski in 1883, and thereby the theoretical conclusions derived from van der Waals' equation were substantially confirmed. The liquefaction

of oxygen and air was achieved through the use of liquid ethylene as a cooling agent, which enabled a temperature of *minus* 140 degrees to be maintained by its steady evaporation *in vacuo*. From this time liquid oxygen and air came to be regarded as the potential cooling agents for future research, commanding as they did a temperature of 200 degrees below melting ice. The theoretical side of the question received at the hands of van der Waals a second contribution, which was even more important than his original essay, and that was his novel and ingenious development of what he calls "The Theory of Corresponding States." He defined the corresponding states of two substances as those in which the ratios of the temperature, pressure and volume to the critical temperature, pressure and volume respectively were the same for the two substances, and in corresponding states he showed that the three pairs of ratios all coincided. From this a series of remarkable propositions was developed, some new, some proving previous laws that were hitherto only empiric, and some completing and correcting faulty though approximate laws. As examples, he succeeded in calculating the boiling-point of carbonic acid from observations on ether vapor, proved Kopp's law of molecular volumes, and showed that at corresponding temperatures the molecular latent heats of vaporization are proportional to the absolute critical temperature, and that under the same conditions the coefficients of liquid expansion are inversely proportional to the absolute critical temperature, and that the coefficients of liquid compressibility are inversely proportional to the critical pressure. All these propositions and deductions are in the main correct, though further experimental investigation has shown minor discrepancies requiring explanation. Various proposals have been made to supplement van der Waal's equation so as to bring it into line with experiments, some being entirely empiric, others theoretical. Clausius, Sarrau, Wroblewski, Batteli, and others attacked the question empirically, and in the main preserved the co-volume (depending on the total volume of the molecules) unaltered while trying to modify the constant of molecular attraction. Their success depended entirely on the fact that, instead of limiting the number of constants to three, some of them have increased them to as many as ten. On the other hand, a series of very remarkable theoretical investigations has been made by van der Waals himself, by Kammerlingh Onnes, Korteweg, Jaeger, Boltzmann, Dieterici, and Rienganum, and others, all directed in the main towards an admitted variation in the value of the

co-volume while preserving the molecular attraction constant. The theoretical reductions of Tait lead to the conclusion that a substance below its critical point ought to have two different equations of the van der Waals type, one referring to the liquid and the other to the gaseous phase. One important fact was soon elicited—namely, that the law of correspondence demanded only that the equation should contain not more than three constants for each body. The simplest extension is that made by Reinganum, in which he increased the pressure for a given mean kinetic energy of the particles inversely in the ratio of the diminution of free volume, due to the molecules possessing linear extension. Berthelot has shown how a "reduced" isothermal may be got by taking two other prominent points as units of measurement instead of the critical coördinates. The most suggestive advance in the improvement of the van der Waals equation has been made by a lady, Mme. Christine Meyer. The idea at the base of this new development may be understood from the following general statement: van der Waals brings the van der Waals surfaces for all substances into coincidence at the point where volume, pressure and temperature are nothing, and then stretches or compresses all the surfaces parallel to the three axes of volume, pressure and temperature until their critical points coincide. But, on this plan the surfaces do not quite coincide, because the points where the three variables are respectively nothing are not corresponding points. Mme. Meyer's plan is to bring all the critical points first into coincidence, and then to compress or extend all the representative surfaces parallel to the three axes of volume, pressure and temperature until the surfaces coincide. In this way, taking twenty-nine different substances, she completely verifies from experiment van der Waals' law of correspondence. The theory of van der Waals has been one of the greatest importance in directing experimental investigation and in attacking the difficult problems of the liquefaction of the most permanent gases. One of its greatest triumphs has been the proof that the critical constants and the boiling point of hydrogen theoretically deduced by Wroblewski from a study of the isothermals of the gas taken far above the temperature of liquefaction are remarkably near the experimental values. We may safely infer, therefore, that if hereafter a gas be discovered in small quantity even four times more volatile than liquid hydrogen, yet by a study of its isothermals at low temperature we shall succeed in finding its most important liquid constants, although the isolation of the real liquid may for the time be im-

possible. It is perhaps not too much to say that, as a prolific source of knowledge in the department dealing with the continuity of state in matter, it would be necessary to go back to Carnot's cycle to find a proposition of greater importance than the theory of van der Waals and his development of the law of corresponding states.

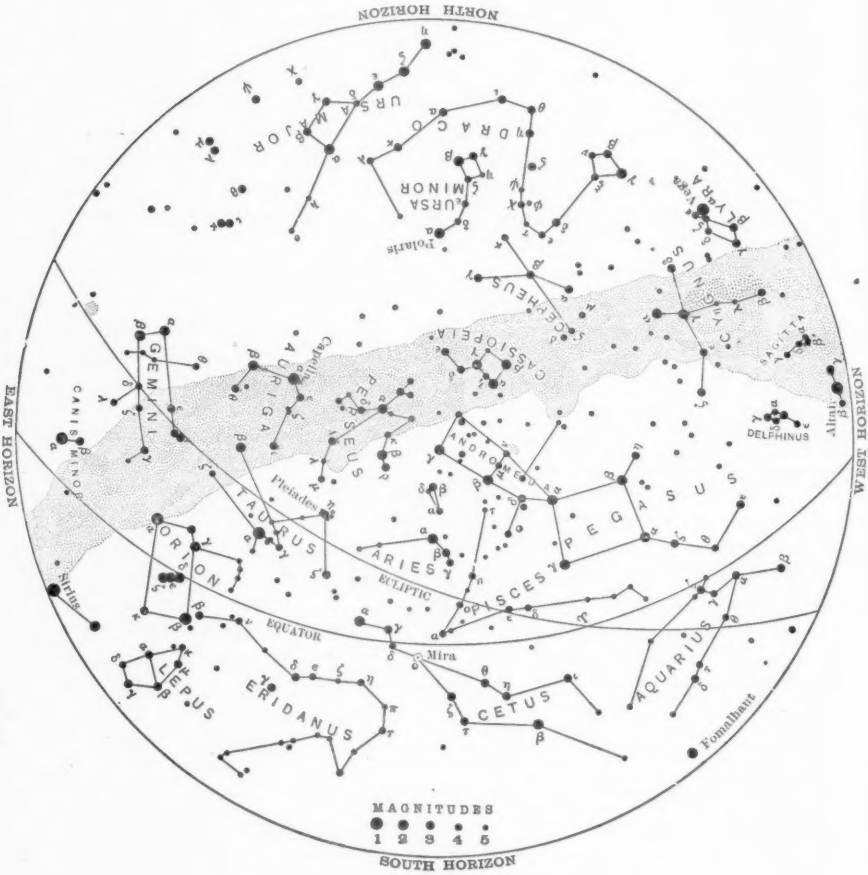
It will be apparent from what has just been said that, thanks to the labors of Andrews, van der Waals, and others, theory had again far outrun experiment. We could calculate the constants and predict some of the simple physical characteristics of liquid oxygen, hydrogen or nitrogen with a high degree of confidence long before any one of the three had been obtained in the static liquid condition permitting of the experimental verification of the theory. This was the more tantilizing, because, with whatever confidence the chemist may anticipate the substantial corroboration of his theory, he also anticipates with almost equal conviction that, as he approaches more and more nearly to the zero of absolute temperature, he will encounter phenomena compelling modification, revision and refinement of formulas which fairly covered the facts previously known. Just as nearly seventy years ago chemists were waiting for some means of getting a temperature of 100 degrees below melting ice, so ten years ago they were casting about for the means of going 100 degrees lower still. The difficulty, it need hardly be said, increases in a geometrical rather than in an arithmetical ratio. Its magnitude may be estimated from the fact that to produce liquid air in the atmosphere of an ordinary laboratory is a feat analogous to the production of liquid water starting from steam at a white heat, and working with all the implements and surroundings at the same high temperature. The problem was not so much how to produce intense cold as how to save it when produced from being immediately levelled up by the relatively superheated surroundings. Ordinary non-conducting packings were inadmissible because they are both cumbrous and opaque, while in working near the limits of our resources it is essential that the product should be visible and readily handled. It was while puzzling over this mechanical and manipulative difficulty in 1892 that it occurred to me that the principle of an arrangement used nearly twenty years before in some calorimetric experiments, which was based upon the work of Dulong and Petit on radiation, might be employed with advantage as well as to protect cold substances from heat as hot ones from rapid cooling. I therefore tried the effect of keeping liquefied gases in

vessels having a double wall, the annular space between being very highly exhausted. Experiments showed that liquid air evaporated at only one-fifth of the rate prevailing when it was placed in a similar unexhausted vessel, owing to the convective transference of heat by the gas particles being enormously reduced by the high vacuum. But, in addition, these vessels lend themselves to an arrangement by which radiant heat can also be cut off. It was found that when the inner walls were coated with a bright deposit of silver the influx of heat was diminished to one-sixth the amount entering without the metallic coating. The total effect of the high vacuum and the silvering is to reduce the ingoing heat to about three per cent. The efficiency of such vessels depends upon getting as high a vacuum as possible, and cold is one of the best means of effecting the desired exhaustion. All that is necessary is to fill completely the space that has to be exhausted with an easily condensable vapor, and then to freeze it out in a receptacle attached to the primary vessel that can be sealed off. The advantage of this method is that no air-pump is required, and that theoretically there is no limit to the degree of exhaustion that can be obtained. The action is rapid, provided liquid air is the cooling agent, and vapors like mercury, water or benzol are employed. It is obvious that when we have to deal with such an exceptionally volatile liquid as hydrogen, the vapor filling may be omitted because air itself is now an easily condensable vapor. In other words, liquid hydrogen, collected in such vessels with the annular space full of air immediately solidifies the air and thereby surrounds itself with a high vacuum. In the same way, when it shall be possible to collect a liquid boiling on the absolute scale at about five degrees, as compared with the 20 degrees of hydrogen, then you might have the annular space filled with the latter gas to begin with, and yet get directly a very high vacuum, owing to the solidification of the hydrogen. Many combinations of vacuum vessels can be arranged, and the lower the temperature at which we have to operate the more useful they become. Vessels of this kind are now in general use, and in them liquid air has crossed the American continent. Of the various forms, that variety is of special importance which has a spiral tube joining the bottom part of the walls, so that any liquid gas may be drawn off from the interior of such a vessel. In the working of regenerative coils such special vessels cannot be dispensed with for the liquefaction of hydrogen.

In the early experiments of Pictet and Cailletet, cooling was

produced by the sudden expansion of the highly compressed gas preferably to a low temperature, the former using a jet that lasted for some time, the latter an instantaneous adiabatic expansion in a strong glass tube. Neither process was practicable as a mode of producing liquid gases, but both gave valuable indications of partial change into the liquid state by the production of a temporary mist. Linde, however, saw that the continuous use of a jet of highly compressed gas, combined with regenerative cooling, must lead to liquefaction on account of what is called the Kelvin-Joule effect; and he succeeded in making a machine, based on this principle, capable of producing liquid air for industrial purposes. These experimenters had proved that, owing to molecular attraction, compressed gases passing through a porous plug or small aperture were lowered in temperature by an amount depending on the difference of pressure, and inversely as the square of the absolute temperature. This means that for a steady difference of pressure the cooling is greater the lower the temperature. The only gas that did not show cooling under such conditions was hydrogen. Instead of being cooled it became actually hotter. The reason for this anomaly in the Kelvin-Joule effect is that every gas has a thermometric point of inversion above which it is heated and below which it is cooled. This inversion point, according to van der Waals, is six and three-quarters times the critical point. The efficiency of the Linde process depends on working with highly compressed gas well below the inversion temperature, and in this respect this point may be said to take the place of the critical one, when in the ordinary way direct liquefaction is being effected by the use of specific liquid cooling agents. The success of both processes depends upon working within a certain temperature range, only the Linde method gives us a much wider range of temperature within which liquefaction can be effected. This is not the case if, instead of depending on getting cooling by the internal work done by the attraction of the gas molecules, we force the compressed gas to do external work as in the well-known air machines of Kirk and Coleman. Both these inventors have pointed out that there is no limit of temperature, short of liquefaction of the gas in use in the circuit, that such machines are not capable of giving. While it is theoretically clear that such machines ought to be capable of maintaining the lowest temperatures, and that with the least expenditure of power, it is a very different matter to overcome the practical difficulties of working such machines under the conditions. Coleman kept a machine delivering air at

minus 83 degrees for hours, but he did not carry his experiments any further. Recently Monsieur Claude, of Paris, has, however, succeeded in working a machine of this type so efficiently that he has managed to produce one litre of liquid air per horse power



THE CONSTELLATIONS AT 9 P. M DECEMBER 1, 1902.

expended per hour in the running of the engine. This output is twice as good as that given by the Linde machine, and there is no reason to doubt that the yield will be still further improved. It is clear, therefore, that in the immediate future the production of

liquid air and hydrogen will be effected most economically by the use of machines producing cold by the expenditure of mechanical work.

PLANET NOTES FOR DECEMBER.

H. C. WILSON.

Mercury will be at superior conjunction Dec. 12 and so will be invisible to the naked eye during this month.

Venus having just passed superior conjunction will emerge from the solar rays as evening star during this month. Just how soon she can be detected in the southwest is hard to say, but probably not before Dec. 15. At the end of the month Venus will set a half hour later than the Sun so that the planet can doubtless be seen for a few minutes each evening. Venus and Mercury will be in conjunction Dec. 22, at 2 A. M. Central Standard time.

Mars will be at quadrature, 90° west from the Sun, Dec. 22, and may be observed in the morning hours. The planet is moving southeastward through the eastern part of Leo.

Jupiter is practically out of view for the winter, although it may be seen at a very low altitude in the southwest for a short time each evening.

Saturn also is practically out of view, being nearer the Sun than Jupiter.

Uranus will be at superior conjunction Dec. 13, and is therefore invisible. Uranus will be in conjunction with Venus Dec. 10 and with Mercury Dec. 13, all three planets being invisible at these times.

Neptune will be at opposition Dec. 24 and so will be in best position for observation during this month and next. The planet is of only the 8th magnitude, so that no one should expect to see it without the aid of a good telescope. Its position Dec. 1 is R. A. $6^h\ 12^m\ 41^s$, Decl. $+\ 22°\ 16'\ 25''$, and on Dec. 31 will be R. A. $6^h\ 09^m\ 07^s$, Decl. $+\ 22°\ 17'\ 27''$. The satellite of Neptune can only be seen with the aid of a large telescope. Its greatest angular distance from the planet is only about 17″, and it completes a revolution around the planet in $5^d\ 21.044^h$. The satellite will be at its greatest distance east and west of the planet on the following dates:

	East. Central Standard Time.		West. Central Standard Time.
	h		h
Dec. 5	3.9 P. M.	Dec. 8	2.9 P. M.
11	12.8 "	14	11.4 A. M.
17	9.9 A. M.	20	8.5 "
23	7.1 "	26	5.7 "
29	4.2 "	32	2.8 "

The Moon.

	Phases.	Rises. (Central Standard Time at Northfield; Local Time 13m less.)		Sets. (Central Standard Time at Northfield; Local Time 13m less.)	
		h	m	h	m
Dec. 7	First Quarter	12	07 P. M.	11	56 P. M.
14-15	Full Moon	4	37 "	7	53 A. M.
22	Last Quarter	12	43 A. M.	12	28 P. M.
29	New Moon	7	17 "	4	58 "

Occultations Visible at Washington.

Date. 1902.	Star's Name.	Magnitude.	IMMERSION. Washington M.T. h m	IMMERSION. Angle from N pt. °	EMERSION. Washington M. T. h m	EMERSION. Angle from N pt. °	Duration. h m
Dec. 4	B.A.C. 7087	6.2	9 44	12	10 13	313	0 29
6	B.A.C. 7717	6.9	9 46	111	10 31	205	0 45
7	Lalande 44872	7.0	10 05	28	10 55	289	0 50
8	21 Piscium	6.1	11 57	69	12 55	253	0 58
12	B.A.C. 1119	6.4	16 53	14	17 09	338	0 16
13	δ^1 Tauri	4.0	6 55	90	7 59	243	1 04
13	δ^2 Tauri	5.7	7 36	129	8 18	205	0 43
13	δ^5 Tauri	5.0	8 23	37	9 18	298	0 55
15	21 Geminorum	6.5	7 01	108	7 54	249	0 53
15	20 Geminorum	6.3	7 04	120	7 55	260	0 51
15	26 Geminorum	5.0	11 46	133	12 48	238	1 02
16	68 Geminorum	5.0	6 28	139	7 02	228	0 34
17	A^1 Cancri	5.6	9 49	112	10 50	269	1 01
20	ν Leonis	4.4	15 37	134	16 55	281	1 18

Phenomena of Jupiter's Satellites.

Central Standard Time.

	h	m					h	m			
Dec. 1	4	19	P. M.	III	Tr. Eg.	Dec. 16	7	13	P. M.	IV	Sh. In.
	5	27	"	III	Sh. In.	19	4	33	"	II	Tr. In.
3	4	09	"	II	Oc. Dis.		6	36	"	II	Sh. In.
4	5	51	"	I	Tr. In.		7	09	"	I	Oc. Dis.
	7	01	"	I	Sh. In.		7	12	"	III	Ec. Re.
	8	11	"	I	Tr. Eg.		7	29	"	II	Tr. Eg.
	9	21	"	I	Sh. Eg.	20	4	23	"	I	Tr. In.
5	4	19	"	II	Sh. Eg.		5	21	"	I	Sh. In.
	6	36	"	I	Ec. Re.		6	43	"	I	Tr. Eg.
8	4	55	"	III	Tr. In.		7	41	"	I	Sh. Eg.
10	6	56	"	II	Oc. Dis.	21	4	02	"	II	Ec. Re.
12	4	00	"	II	Sh. In.		4	54	"	I	Ec. Re.
	4	43	"	II	Tr. Eg.	24	6	33	"	IV	Oc. Dis.
	5	08	"	I	Oc. Dis.	27	6	24	"	I	Tr. In.
	6	55	"	II	Sh. Eg.		7	17	"	I	Sh. In.
	8	31	"	I	Ec. Re.	28	6	41	"	II	Ec. Re.
13	4	42	"	I	Tr. Eg.		6	49	"	I	Ec. Re.
	5	46	"	I	Sh. Eg.						

NOTE.—In. denotes ingress; Eg., egress; Dis., disappearance; Re., reappearance; Ec., eclipse; Oc., occultation; Tr., transit of the satellite; Sh., transit of the shadow.

COMET AND ASTEROID NOTES.

Elements and Ephemeris of Comet *b*, 1902.—In *A. N.* 3821 Mr. Elis Strömgren gives elements and an ephemeris depending upon observations, Sept. 1, Sept. 20 and Oct. 8. From the ephemeris it appears that the comet may possibly be observed in northern observatories during the latter half of December but that during the most of January it will be too far south and can be observed only from the southern latitudes. In February it will again come into view from our part of the globe.

ELEMENTS.

$T = 1902$, Nov. 23.88925, Berlin M. T.
$\omega = 152^\circ\ 57'\ 28''.2$
$\Omega = 49\ 21\ 07\ .5$
$i = 156\ 21\ 09\ .8$
$\log q = 9.603246$

EPHEMERIS.

Berlin Midn. 1902-3.	R. A. h m s	Decl. ° ′	log *r*.	log Δ.	Br.
Dec. 9	15 22 48	−25 3.2	9.7578	0.1237	9.3
10	19 47	25 30.4			
11	16 46	25 57.9			
12	13 46	26 25.6			
13	10 46	26 53.7	9.8099	0.1068	7.9
14	7 44	27 22.1			
15	4 42	27 51.0			
16	15 1 38	28 20.3			
17	14 58 32	28 50.0	9.8580	0.0867	6.9
18	55 23	29 20.4			
19	52 11	29 50.9			
20	48 54	30 22.1			
21	45 33	30 53.9	9.9019	0.0636	6.3
22	42 6	31 26.4			
23	38 33	31 59.5			
24	34 52	32 33.2			
25	31 4	33 7.6	9.9417	0.0381	5.9
26	27 8	33 42.6			
27	23 2	34 18.2			
28	18 44	34 54.4			
29	14 15	35 31.1	9.9781	0.0105	5.7
30	9 34	36 8.5			
31	14 4 38	36 46.4			
Jan. 1	13 59 28	37 24.8			
2	54 0	38 3.6	0.0112	9.9814	5.6
3	48 14	38 42.7			
4	42 10	39 22.0			
5	35 44	40 1.3			
6	28 55	40 40.5	0.0416	9.9518	5.5
7	21 42	41 19.4			
8	14 4	41 57.6			
9	13 5 58	42 34.9			
10	12 57 24	43 11.0	0.0697	9.9231	5.6
11	48 20	43 45.5			
12	38 48	44 18.0			
13	28 44	44 48.0			
14	12 18 9	−45 15.0	0.0956	9.8975	5.6

New Asteroids.—The following have been added to the list of new planets since our last note:

	Discoverer.	Place.	Local M. T.	R. A. h m	Decl. ° ′	Mag.
1901 JV	Wolf	Heidelberg	Oct. 7 10 38.8	2 09.7	+10 55	12.5
JW	Wolf	"	7 13 25.8	2 05.2	+ 3 18	13.0
JX	Wolf	"	7 13 25.8	1 52.9	+ 2 55	13.5
JY	Wolf	"	24 12 10.3	1 55.2	+12 14	13.5
JZ	Wolf	"	24 12 10.3	1 59.2	+12 59	13

JU was found to be identical with (109) Dione.

Ephemeris of Planet (48) Doris.—In *A. N.* 3824 Mr. M. Shilow, of Pulkowa gives an ephemeris of the asteroid (48) Doris extending from Nov. 20 to Dec. 14. Opposition occurs Dec. 5, when the magnitude of the asteroid will be 10.6.

EPHEMERIS OF PLANET (48) DORIS.

Berlin Midn.	R. A. h m s	Decl. ° ′	log Δ.	Aberrat'n Time. m s
Dec. 2	4 51 38	+13 24.6	0.2874	16 05
4	49 56	13 19.9	2872	4
6	4 48 14	+13 15.4	0.2872	16 4

EPHEMERIS OF PLANET (48) DORIS.—Continued.

Berlin Midn.	R. A.	Decl.	log Δ	Aberrat'n Time.
	h m s	° ′		m s
Dec. 8	4 46 33	+13 11.3	0.2874	16 5
10	44 53	13 07.3	2882	6
12	43 13	13 03.6	2890	8
14	4 41 35	+13 00.4	0.2901	16 11

VARIABLE STARS.

Minima of Variable Stars of the Algol Type.

[Greenwich Mean Time beginning with midnight. The hours greater than 12 are those of the afternoon. To obtain Eastern Standard time subtract 5 hours; for Central Standard subtract 6 hours, etc.]

U Cephei.

	d	h
Dec.	3	7
	5	19
	8	7
	10	18
	13	6
	15	18
	18	6
	20	18
	23	6
	25	17
	28	5
	30	17

Algol.

Dec.	1	17
	4	14
	7	11
	10	8
	13	5
	16	1
	18	22
	21	19
	24	16
	27	13
	30	9

λ Tauri.

Dec.	3	19
	7	18
	11	17
	15	16
	19	14
	23	13
	27	12
	31	11

R Canis Majoris

Dec.	1	14
	2	18
	3	21
	5	0
	6	3
	7	6
	8	10
	9	13
	10	16

R Can. Maj. Con.

	d	h
Dec.	11	20
	12	23
	14	2
	15	5
	16	9
	17	12
	18	15
	19	18
	20	22
	22	1
	23	4
	24	7
	25	10
	26	14
	27	17
	28	21
	30	0
	31	3

S Cancri.

Dec.	7	2
	16	14
	26	2

S Antliæ.

Period $7^h\ 46^m.8$

Dec.	1	22
	2	21
	3	21
	4	20
	5	19
	6	19
	7	18
	8	17
	9	17
	10	16
	11	15
	12	15
	13	14
	14	13
	15	13
	16	12

S Antliæ Con.

	d	h
Dec.	17	11
	18	11
	19	10
	20	9
	21	9
	22	8
	23	7
	24	7
	25	6
	26	5
	27	5
	28	4
	29	3
	30	3
	31	2

δ Librae.

Dec.	3	6
	5	14
	7	22
	10	5
	12	13
	14	21
	17	5
	19	13
	21	21
	24	5
	26	12
	28	20
	31	4

U Coronæ.

Dec.	1	12
	4	23
	8	10
	11	20
	15	7
	18	18
	22	5
	25	16
	29	3

RX Herculis.

Dec.	1	22
	2	19
	3	17
	4	14

RX Her. Con.

	d	h
Dec.	5	11
	6	9
	7	6
	8	3
	9	1
	9	22
	10	20
	11	17
	12	14
	13	12
	14	9
	15	6
	16	4
	17	1
	17	22
	18	20
	19	17
	20	14
	21	12
	22	9
	23	6
	24	4
	25	1
	25	22
	26	20
	27	17
	28	14
	29	12
	30	9
	31	6

Z Herculis.

Dec.	1	10
	3	9
	5	10
	7	9
	9	9
	11	8
	13	9
	15	8
	17	9
	19	8
	21	8
	23	7
	25	8
	27	7
	29	8
	31	7

SY (V^3) Cygni.

	d	h
Dec.	2	14
	8	14
	14	14
	20	14
	26	14

SW (U^3) Cygni.

Dec.	2	6
	6	20
	11	9
	15	23
	20	13
	25	3
	29	17

W Delphini.

Dec.	4	10
	9	6
	14	1
	18	20
	23	16
	28	11

Y Cygni.

Dec.	2	5
	3	21
	5	5
	6	21
	8	5
	9	21
	11	5
	12	21
	14	5
	15	21
	17	5
	18	21
	20	5
	21	21
	23	5
	24	21
	26	5
	27	21
	29	5
	30	21

Maxima of U Pegasi.

Period $4^h\ 29^m.8$. The minimum occurs $2^h\ 15^m$ after the maximum.

	d	h		d	h		d	h		d	h
Dec.	1	2	Dec.	9	4	Dec.	17	1	Dec.	25	2
	2	1		10	2		18	4		26	1
	3	4		11	1		19	2		27	3
	4	2		12	4		20	1		28	2
	5	1		13	2		21	3		29	0
	6	4		14	1		22	2		30	3
	7	2		15	4		23	1		31	2
	8	1		16	2		24	3			

Variable Stars of Short Period not of the Algol Type.

	Minimum.		Maximum.			Minimum.		Maximum.	
		h		h			h		h
Y Sagittarii	Dec. 1	12	Dec. 3	7	X Cygni	Dec. 15	19	Dec. 22	14
W Virginis	1	16	9	20	β Lyrae	16	15	18	17
β Lyræ	3	17	6	19	δ Cephei	16	21	18	12
η Aquilæ	4	12	6	18	T Vulpeculæ	18	13	19	22
ζ Geminorum	4	17	9	17	η Aquilæ	18	21	21	3
T Vulpeculæ	5	6	6	15	W Virginis	18	23	27	3
S Sagittæ	5	12	8	22	W Geminorum	21	20	24	11
δ Cephei	6	4	7	19	δ Cephei	22	6	23	21
W Geminorum	6	8	8	23	T Vulpeculæ	23	0	24	9
X Sagittarii	6	8	9	5	β Lyræ	23	2	26	11
T Vulpeculæ	9	17	11	2	ζ Geminorum	25	0	30	0
β Lyræ	10	3	13	13	T Monocerotis	25	3	33	1
δ Cephei	11	12	13	3	η Aquilae	26	1	28	7
η Aquilæ	11	17	13	23	T Vulpeculae	27	10	28	19
S Sagittae	13	21	17	7	δ Cephei	27	15	29	6
W Geminorum	14	2	16	17	β Lyræ	29	13	32	15
T Vulpeculæ	14	3	15	12	W Geminorum	29	13	32	3
ζ Geminorum	14	20	19	20	T Vulpeculæ	31	21	33	6

New Algol-Type Variable 14.1902, Persei.—In *A. N.* 3820 Mr. A. Stanley Williams gives elements of a new variable star of the Algol type The star is

BD + 41°,504 R. A. $2^h\ 30^m\ 50^s$ Decl. + 41° 34′.3 (1855)

It is normally of the magnitude 9.4, but at minimum descends nearly to 12. Mr. Williams determines the elements from visual observations made Sept. 13, 16 and 19, 1902 and photographs Jan. 25, Mar. 12, Mar. 18 and Dec. 18, 1901:

Min. = 1902 Sept. 16, $16^h\ 38^m$ Gr. M. T. + $3^d\ 1^h\ 21^m\ 32^s.23$ E
= J.D. 2416009.6934 + $3^d.056623$ E.

He gives the following ephemeris for every fifth minimum:

E.	Date.	Gr. M. T.		E.	Date.	Gr. M. T.	
		h	m			h	m
207	1902 Oct. 17	6	14	247	1903 Feb. 16	12	35
212	Nov. 1	13	01	252	Mar. 3	19	23
217	16	19	49	257	19	2	11
222	Dec. 2	2	37	262	Apr. 3	8	58
227	17	9	25	267	18	15	46
232	1903 Jan. 1	16	12	272	May 3	22	34
237	16	23	00	277	19	5	21
242	Feb. 1	5	48				

MULTIPLES OF THE PERIOD.

	d	h	m		d	h	m
1 =	3	1	21.5	3 =	9	4	04.6
2 =	6	2	43.1	4 =	12	5	26.1

GENERAL NOTES.

Visibility of Eros.—A letter lately received from Professor Bailey states that Eros was photographed with the Bruce telescope on July 8, 1902. The telescope was made to follow a star by means of an eye piece adjoining the plate, while a motion was given to the latter equal to the computed motion of Eros. The stars accordingly leave trails having a direction and length corresponding to the motion of Eros, while the planet appears as a minute dot, the entire light being concentrated for the whole time of exposure upon a few silver particles. A second photograph confirmed this observation. So far as known, the first visual observation of Eros, since its recent conjunction with the Sun, was obtained by Professor H. A. Howe at the Denver Observatory on August 2, 1902, as announced in the Harvard *Bulletin* of August 5, 1902. It will be remembered that the first photograph of Eros after its conjunction in 1899 was also obtained with the Bruce telescope on April 28, 1900, by the method described above. It was first seen on June 6, 1900, at the Denver Observatory, and later at the Arcetri Observatory on June 30, 1900. In like manner, it was followed after the opposition of 1900, until March 12, 1901, at Arcetri, until June 17, 1901, at Denver, and until September 9, 1901, at Arequipa, with the Bruce telescope.

E. C. P.

Williams' New Algol Variable 13.1902.—In order to identify the Algol variable, 13.1902, recently announced by Mr. A. S. Williams (*A. N.* 159, 309), its position was marked on several of the Draper Memorial photographs. On one of these, taken 1893, July $11^d\ 18^h\ 10^m$, G. M. T., the star appeared fainter than normal. On Mr. Williams' scale its magnitude was about 11.3 or a little nearer in brightness to his star *d*, than to his star *b*. It is also very nearly equal in brightness to the star which follows the variable about 45^s, north $6'.8$. This would indicate that the time of minimum preceded or followed the time of taking the photograph by about three hours, assuming the light curve described by Mr. Williams. The formula he gives indicates for $E = -918$, a time of minimum J. D. $2{,}412{,}656.720 = 1893$, July $11^d\ 17^h\ 17^m$, G. M. T., omitting his last three decimal places which appear to be indeterminate.

This photograph, therefore, gives a correction to the ephemeris of $+\ 4^h$ or $-\ 2^h$. An examination of the other plates of this region would distinguish between these two values, and determine the correct one with much greater accuracy. Probably we have at least one hundred photographs of this region, although the star may be too faint to appear on a portion of them. On one tenth of the photographs the star should be below its normal brightness. A precise correction to the ephemeris can be found from each of these, if not too near maximum or minimum, when the photographic light curve has been found, as can now be readily done. Unfortunately, the pressure of other work will probably prevent the continuation of this research at present. As it is, the observation given above lengthens the period of observation from less than ten months to about nine years, and increases the accuracy with which the period can now be determined in nearly the same proportion. E. C. P.

Early Observations of Nova Persei, No. 2.—As the Nova is diminishing in light it becomes necessary to use comparison stars so faint that they are not contained in the Harvard Annals, Volume XLV or other photometric catalogues. A sequence has accordingly been selected which is given in Table I. The designation, is followed by the number, number of grades, difference in right as-

cension, and difference of declination from the Nova, taken from Hagen's Second Catalogue. The sixth column gives the photometric magnitude, found for the stars *b* to *f* from comparisons by Professor Wendell with star *a*. Constructing a curve with coördinates taken from the second and sixth columns, we have the means of converting the estimates of Hagen into magnitudes on the photometric scale. The seventh column gives the residual found by subtracting the magnitude given in the sixth column from the Hagen magnitude thus formed. Table II gives the photometric magnitude corresponding to various values of Hagen's grades. The fainter magnitudes found by interpolation are somewhat uncertain.

TABLE I.

SEQUENCE OF COMPARISON STARS.

Decl.	H.	Gr.	$\Delta\alpha$	$\Delta\delta$	Magn.	H—P.
			s	′		
a	20	67	— 21	+ 4.8	9.10	+ .03
b	32	84	+ 43	+ 8.7	9.71	+ .19
c	34	92	— 65	+ 3.4	10.57	— .32
d	42	111	+ 35	+ 0.2	11.03	+ .01
e	46	133	— 82	+ 6.3	11.94	— .08
f	49	145	— 24	— 1.5	12.23	+ .03
g	56	161	— 17	+ 2.4	.....	...
h	65	178	+ 42	+ 4.8	.....	...
k	66	179	+ 33	— 4.1	.....	...
l	68	185	+ 34	+ 1.5	.....	...
m	74	199	+ 21	+ 1.6	.....	...
n	77	209	+ 13	+ 1.0	.....	...
o	80	...	— 3	— 0.5	.....	...

Table II furnishes the means of determining the limiting magnitude below which the Nova must have been before its discovery. The last photograph taken before it was found on February 21, 1902, was obtained by Mr. A. S. Williams on February 20. It is reproduced in *Knowledge*, XXIV, 152. All stars included in the region covered by the print, and brighter than Hagen No. 42, are shown except Nos. 29, 34, 36, 38, and 39. The absence of No. 39 is perhaps due to the proximity of No. 28. Stars of the magnitude 10.9 are therefore shown, and we may hence infer that the Nova was below this limit on February 20. Several defects appear on this print which cannot be distinguished from stars. The next photograph preceding this was obtained at this Observatory, and is shown in Figure 1 of Circular No. 57. This print shows all stars brighter than No. 49, except No. 39. The Nova must therefore have been fainter than the magnitude 12.0 on that date.

TABLE II.

RELATION OF HAGEN'S GRADES TO MAGNITUDES.

Grades.	Magnitudes.	Grades.	Magnitudes.	Grades.	Magnitudes.	Grades.	Magnitudes.
0	6.56	50	8.39	100	10.59	150	12.42
10	6.90	60	8.82	110	11.00	160	12.72
20	7.25	70	9.27	120	11.39	170	13.00
30	7.61	80	9.72	130	11.76	180	13.25
40	7.99	90	10.16	140	12.10	190	13.48

About a year ago Father Zwack of the Georgetown College Observatory called my attention to a faint star which appeared on one of our early photographs so near the position of the Nova that careful measurements were required to determine whether the positions are identical or not. A measurement of several of the early plates gave the magnitudes of this object on October 26,

December 2, 1890, January 20, March 11, December 10, 1891, January 25, 1893, October 11, 1894, October 17, 1897, and March 7, 1900, as 12.95, 13.37, <13.7, <13.4, <13.7, 14.06, 13.15, 13.46 and 13.36, respectively. The images of this star on the photographs taken in 1890 are somewhat uncertain, but a comparison of the photographs taken in 1893 and 1894 leaves little doubt of the variability of this object. Measurements of its position were made on the last three photographs mentioned above. Taking the position in which the Nova appeared as an origin, the values of x for this star are $-1''.6$, $+1''.2$, and $+0''.2$, those of y, $+1''.3$, $-1''.0$, and $-0''.2$, respectively. These measures are based on the positions of the stars Nos. 20, 56, 77, 78, 79, 80, and 81, determined micrometrically at the Lick Observatory.

The object announced by M. S. Blajko, *A. N.* 157, 193, which according to his measures, followed the Nova $0^s.31$, south $7''$, on January 30, 1899, is doubtless identical with this object. Hagen's double star, No. 69, whose position is $40''$ distant from the Nova, does not appear on any of these photographs, although much fainter stars are shown.

We may therefore conclude that a star whose light varied from the thirteenth to the fourteenth magnitude was visible for several years within one or two seconds of arc of the Nova, the difference in position being less than the errors of measurement. EDWARD C. PICKERING.

HARVARD COLLEGE OBSERVATORY,
Circular No. 66, October 31, 1902.

Total Lunar Eclipse Oct. 16, 1902.—The following observations of the eclipse of Oct. 16th, 1902 were made with the five inch finder of the telescope at Chamberlain Observatory, University Park, Colorado. The magnifying power employed was 40 diameters.

Each time was noted by starting a stop-watch, which was immediately afterward, compared with a standard clock. This watch indicated fifths of seconds. The results are given below in local mean time:

	h	m
Eclipse began	9	17.5
Eclipsed portion became visible	9	49.7
Totality began	10	22.1
Eclipse ended	12	50.9

The following immersions of two stars of the 9th magnitude were noted. The position angle of each star was about 90° with reference to the Moon's disc, so that a spider web placed tangent to the Moon's limb at the point of disappearance would have stood at nearly 0° in position angle. More accurate values of these angles can be found in the reports of Dr. Howe and Dr. Ling each of whom measured them with a position micrometer. The first star disappeared at $11^h\ 35^m\ 21^s.4$; the second star at $11^h\ 39^m\ 2^s.6$. D. S. SWAN.

Observations of the Eclipse of Oct. 16, 1902, by Students of the University of Denver.—The following observations were made by students in the University of Denver, most of whom used telescopes of less than 2 inches aperture. Messrs. A. S. Clark and J. G. Todd observed entirely with the naked eye, and noted only the nearest minutes. Other cases of naked eye observations are specified. The students had been requested particularly to notice when the Moon's limb began to darken because of the penumbra, and how soon after first contact the eclipsed portion became visible. All times noted (except those of Messrs. Clark and Todd) were taken from a clock which had an error of

over a minute, of which no observer was aware. The observations have been corrected for the clock-error, and are classified below; they are in University Park M. T.

1. The darkening of the Moon's limb becomes noticeable.

	h	m		h	m
Gertrude Brink	9	14.2	J. O. Howe	9	3.4
A. S. Clark	9	8	Irene Hunter	9	13.7
E. A. Hemphill	9	14.2	J. B. Ruple	9	14.7
H. S. Howe	9	7.2	J. G. Todd	9	2
			Norine Wilson	9	13.5

2. The Moon encounters the umbra.

	h	m		h	m
Gertrude Brink	9	16.9	J. G. Howe	9	17.1
A. N. Chapman	9	13.1	Irene Hunter	9	17.3
A. S. Clark	9	16	J. B. Ruple	9	17.3
E. A. Hemphill	9	17.0	J. G. Todd	9	16+
H. S. Howe	9	17.3	Norine Wilson	9	16.8

3. Eclipsed portion becomes visible in the telescope.

	h	m		h	m
E. A. Hemphill	9	49.7	J. B. Ruple	9	47.8
H. S. Howe	9	48.7	Norine Wilson	9	50.0

4. Eclipsed portion becomes visible to the naked eye.

	h	m		h	m
Gertrude Brink	9	50.3	E. A. Hemphill	9	53.0
A. N. Chapman	9	52.4	J. B. Ruple	9	47.8
			Norine Wilson	9	50.4

5. Totality begins.

	h	m		h	m
A. N. Chapman (naked eye)	10	20.0	H. S. Howe	10	21.0
			Irene Hunter	10	20.0
A. S. Clark	10	23	J. B. Ruple	10	21.4
E. A. Hemphill	10	20.2	J. G. Todd	10	22

6. Totality ends.

	h	m		h	m
A. N. Chapman (naked eye)	11	48.4	E. A. Hemphill	11	46.0
			J. B. Ruple	11	44

7. Eclipse ends.

	h	m		h	m
E. A. Hemphill	12	50.4	J. B. Ruple	12	50±

From the foregoing it appears that no darkening of the Moon's face was noticed by the students till about 7 minutes (on the average) before the eclipse began. In Professor Young's General Astronomy the interval is given as "half an hour or so." Also half an hour elapsed after the beginning of the eclipse, before the eclipsed portion became visible to the naked eye. This time would, of course, vary a good deal in different eclipses. HERBERT A. HOWE.

Notes on the Lunar Eclipse of Oct. 16, 1902.—The following observations of the lunar eclipse of Oct. 16, 1902 were made with the 20 inch refractor of the Chamberlin Observatory, and with its 5-inch finder. The magnifying power on the large telescope was 200 diameters; on the finder it was 40 diameters. All the times noted are given in University Park mean time.

At $9^h\ 4^m$ the penumbral darkening was plain in the finder, but doubtful to the naked eye, because of the presence of an extensive sea where the greatest darkening ought to be.

At $9^h\ 17^m.2$ it was certain that the Moon had encountered the true shadow, though the darkening came on quite gradually. At $9^h\ 19^m.0$ a part of the Moon had actually disappeared in the large telescope. A light haze cloud had just

covered the Moon, but I watched for a few minutes and became certain that no details could be seen within the shadow, though they were plain outside of it. That is, the eclipsed portion was totally invisible. The shadow appeared yellowish brown through the light clouds.

With the finder, at about $9^h\ 50^m$ the whole of the eclipsed portion was visible. But at this time the large telescope revealed only a portion of the darkened area, it being impossible to see all of the darkened limb. In the finder the (apparent) upper portion of the eclipsed area looked reddish brown, and was much brighter than the lower limb.

To the naked eye at $10^h\ 4^m$ the lower part of the eclipsed portion (upper in the telescopes) was quite bright and reddish, while the upper left hand part was quite dark, the outline being barely visible. The finder and the large telescope corroborated the naked eye view, except that at no time yet could all of the eclipsed limb of the Moon be seen with the large telescope.

At $10^h\ 7^m$ the dark limb first became visible in its entirety in the large telescope, though it had been visible for several minutes before this in the finder and to the naked eye. At $10^h\ 14^m$ the top and bottom of the shadow were bright to the naked eye, while the central portion was dark.

There was considerable difficulty in deciding just when the eclipse became total, but a note was made to the effect that the Moon was certainly completely immersed at $10^h\ 22^m.1$. During totality a number of immersions of faint stars were observed; the details of these observations will be given later.

The time for the ending of totality seemed exceptionally hard to determine, as the Moon's limb grew quite bright at the point where the direct sunlight was first to appear, some minutes prior to the real end of totality. The end had surely come at $11^h\ 48^m.4$.

At $12^h\ 4^m$ the part farthest from the illuminated portion was red; between the two was a dark green streak; (I think that this observation was made with the naked eye). The outline of the eclipsed portion of the limb was hard to see with the large telescope at $12^h\ 21^m$, though plain to the naked eye.

At $12^h\ 25^m$ a portion of the dark edge near one cusp was invisible in the large telescope, and most of the eclipsed portion was seen with difficulty. At $12^h\ 31^m$ the eclipsed portion had lost its redness in the large telescope, and was very hard to see. It had also almost vanished for the naked eye. The eclipsed portion was invisible to the naked eye at $12^h\ 36^m$, and a part of it could be faintly seen in the large telescope. At $12^h\ 45^m$ all of the eclipsed portion was seen in the large telescope though no trace of it was visible to the naked eye. The eclipse was certainly over at $12^h\ 51^m$.

During totality the times of immersion for several fainter stars were noted, a micrometer wire being placed nearly tangent to the Moon's limb at the point of disappearance of each star. The angles given below are the apparent position angles of the stars from the center of the Moon, or the real angles from the north point of the Moon's limb around toward the east.

Magn.	University Park M. T.			Position Angle.		Magn.	University Park M. T.			Position Angle.	
	h	m	s	°	′		h	m	s	°	′
11	10	44	24.4	99	0	10	11	35	21.7	87	8
11	10	54	44.3	104	50	11.5	11	37	55.2	95	47
11	11	1	16.7	50	27	10	11	39	6.7	87	13
10.5	11	25	41.3	34	0	11.5	11	53	0.9	114	40

HERBERT A. HOWE.

UNIVERSITY PARK, Colorado.

The Eclipsed Moon in a Four-Inch Telescope.—Total eclipses of the Moon having eluded San Francisco observers for many years past the clear sky of the evening of Oct. 16th was greeted with joy by many to whom the often described lurid coppery light was but a picture of the imagination. The Moon passed through the penumbral region without any noticeable diminution of light but some minutes before 8:17, the predicted hour of first contact with the dark terrestrial shadow the east limb near Grimaldi grew dim and its symmetry distinctly impaired at the anticipated moment.

Soon Aristarchus, Kepler and Tycho were immersed in gloom, and when more than half the disk was eclipsed a pinkish tint appeared curving round the eastern limb. It spread to the tracks round Tycho, and even to the unaided eye the lurid coppery light had become an impressive reality. By a remarkable co-operation of refraction and lunar distance, nature like a skilled artist contrives a special light for the sunless disk. When it had thus become the very goal of the atmospheric glow encircling Earth near the borderland of night and day, the tint before, and for some time after totality had commenced, was more pink than red. A slight mingling of direct sunlight with the refracted red rays created an exquisite pinkish luminosity on the west limb and afterwards on the east while they were adjacent to the penumbral regions. Indeed in those stages the lunar sphere conveyed an impression of a translucent body illuminated by its own internal fires. At first the central part of the completely eclipsed Moon was rendered indistinct by a semi-circular shade with a curving gap in it just north of Tycho, but as the orb advanced, the shade assumed an oblong form and soon disappeared as it receded from the edge of the Earth's shadow. About 10:00 P. M. when midway the time-honored coppery hue had full sway though it is probable that a clear atmosphere near the base of the great shadow enlivened its rays and revealed lunar topography with unexpected distinctness, especially in a telescope. The color of the seas closely resembled a dull grey object such as grey paper on which light through a red lamp falls. The streaks were discernible, even those round Copernicus, and the latter crater was more conspicuous than Tycho. Aristarchus as usual outshone all other features of the lunar landscape. Our eclipsed satellite seemed a strange visitor as it hung on high with mottled surface framed in by the small stars of the constellation of the Fishes, which shone through the depths of the terrestrial shadow; and the entire phenomenon was an object lesson in light and shade on a stupendous scale.

ROSE O'HALLORAN.

San Francisco, Oct. 18th, 1902.

Partial Eclipse of Jupiter—Satellite I by Satellite III, October 19th, 1902.—On October 19th I observed shadow of Satellite III and later shadow of Satellite I, both on the planet at the same time. I intended to watch the conjunction of the shadows but was called away. When I returned the shadow of Satellite I was visible but that of Satellite III could not be seen.

At 8:21 W. M. T. I noticed that Satellite I had decreased its light one-third its usual magnitude, and it remained so at least ten minutes. This was so unexpected that I failed to realize at once what the explanation of this might be, and so was obliged to estimate the time of obscuration.

The observations were made with an Alvan Clark refractor, 6½-inch object glass, power 180, sky clear, seeing good. My theory in accounting for being able to see one shadow and not the other for the time mentioned is that one shadow was partially superimposed upon the other. The *Nautical Almanac* gives a

difference of time of egress of shadows of Satellites I and III, of eleven minutes. I am not aware that a partial or a total eclipse of one of Jupiter's satellites by another has ever been recorded. T. A. LAWES.

DANVILLE, Ill.

Proper Motion of the Double Star BD. + 24°.2733.—In *A. N.* 3824 Mr. A. Verschaffel, Director of the Observatory of Abbadia, calls attention to the considerable movement of the components of the double star BD. +24°.2733, as shown by the comparison of meridian circle observations made at Abbadia in 1900 with the places given the Berlin A. G. Catalogue. When reduced to 1900.0 the positions from the two sources are as follows:

	h	m	s	°	′	″	Epoch.	
+ 24°.2733[1]	14	21	03.93	+ 24	06	19.3	1880.9	Berlin
	14	21	05.06	+ 24	05	57.3	1900.4	Abbadia
+ 24°.2733[2]	14	21	07.14	+ 24	06	31.3	1881.1	Berlin
	14	21	08.27	+ 24	06	09.1	1900.9	Abbadia

These data if verified give a yearly proper motion for both stars of about $0^s.0580$ in R. A. and $-1''.128$ in Decl., or $1''.38$ in an arc of a great circle, in the direction 144° 51′ from north. The stars are both of the 9th magnitude.

Aldis' Tables of $\frac{1}{2}(\theta + \cos\theta)$.—In *Monthly Notices* of the R. A. S. Vol. LXII, No. 9, Mr. W. Steadman Aldis gives an extensive set of tables of the function $\frac{1}{2}(\theta + \cos\theta)$. The values of the function are given to the ten thousandth part of a second of arc for each minute from $-90°$ to $+90°$ of θ and rules are given for the use of the table for values of θ extending to $\pm 180°$. First and second differences are given.

The most important use of the tables is in solving Kepler's equation

$$M = E - e \sin E$$

which the author transforms in the following ingenious manner. Putting $e = \sin\phi$

$$\begin{aligned} M &= E - \sin\phi \sin E \\ &= \tfrac{1}{2}[\phi + E + \cos(\phi + E)] - \tfrac{1}{2}[\phi - E + \cos(\phi - E)]. \end{aligned} \qquad (1)$$

and the two parts of the second member of the equation are both of the form $\frac{1}{2}(\theta + \cos\theta)$. The quantity ϕ being known, the problem resolves itself into finding the two angles equidistant from ϕ, above and below, for which the values of the function differ by the known quantity M. Two or three approximations usually suffice to give an accurate value of θ and thus of E.

The same tables may be used to find r in the equation

$$r = a(1 - e\cos E) = a(1 - \sin\phi\cos E)$$

which can be transformed into

$$r = a\left\{\frac{1 - \sin(\phi + E)}{2} + \frac{1 - \sin(\phi - E)}{2}\right\}. \qquad (2)$$

The two parts of the coefficient of a in the last equation being the derivatives of equation (1) with respect to $\phi + E$ and $\phi - E$, are very nearly the tabular differences opposite $\theta = \phi + E$ and $\theta = \phi - E$, divided by 60.

The tables may also be used for finding the elements of an elliptic orbit, when two focal distances, the angle between them, and the time occupied in passing from one position to the other are known.

Total Eclipse of the Moon Oct. 16, 1902.—The following observations of the total eclipse of the Moon on October 16, 1902 were taken with the six-inch refractor in the students' Observatory at the University of Denver, the magnifying power being approximately 60:

	h	m
First contact	9	17.2
Total eclipse begins	10	21.3
Total eclipse ends	11	47.5
Last contact	12	50.5

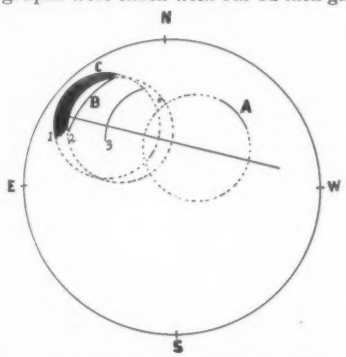
During the total eclipse two stars of the 9th magnitude were observed at immersion, as follows:

	h	m	s		°
First star	11	35	21.2	Position angle	94.7
Second star	11	39	2.8	Position angle	87.8

CHAS. J. LING.

Total Eclipse of the Moon Oct. 16, 1902.—The interesting phenomenon of a dark band running across the totally eclipsed Moon was seen here and drawn very nearly as seen by Dr. Wilson in the POPULAR ASTRONOMY for November. A series of photographs taken here, I think throws light on the cause of it.

In the early part of the eclipse during the partial phase a series of photographs were taken with our 12-inch glass cut down to 6-inch aperutre. With the primary image enlarged to 4½ inches in diameter a number or photographs were taken with one-half second exposure. When totality began the dark band was so distinct that it was thought it might be photographed. The telescope was tried with full aperture and an exposure of 25 seconds. Nothing could be developed on this plate. An instantaneous isochromatic plate was then exposed for 1 minute and 45 seconds. No impression was found on this plate. The enlarging apparatus was then removed and an exposure of 2 minutes 15 seconds made on a Cramer Crown plate ses. 80. This plate shows the Moon as a very faint and very narrow crescent. Its position in the Earth's shadow and its size are represented by the arc *A* in the accompanying diagram.



An exposure of 23½ minutes was then made during which the eastern limb of the Moon passed from No. 3 to No. 2; the resulting image was still only a crescent but this time in the NE. quadrant. The size and shape of the picture is represented by *B*. The light that produced *B* might have come from anywhere between 2 and 3 but that it actually came from tne position where *B* is placed is an inference from the last picture.

This exposure was for 7 minutes and was ended at 4 minutes before the totality was over. This photograph shows the whole Moon very dimly but a broad crescent (*c* in diagram) has the film entirely blackened.

Assuming *C* to be equally dense with the pictures taken during the partial phase the amount of actual light where the crescent *c* lies on the Earth's shadow would be less than 1/34.000 of the full moonlight.

The photographs show that the blue or violet rays are relatively strong for

a distance from the edge of the shadow of about 1/12 its diameter. A good illumination of the greater refraction of these rays by the Earth's atmosphere. At 1/12 of the diameter of the shadow from the edge the photographic power ends abruptly. It seems to me these photographs explain the peculiar phenomenon visible at the beginning of totality.

The south side of the Moon is naturally very bright having so many craters and few seas as reference to a photograph of the full Moon will show. The illumination on the north side was due to the proximity of that side to the edge of the Earth's shadow. This was photographed as a crescent at *A*. By reference to Dr. Wilson's drawing it will be seen that he makes the northwestern side of the Moon not the northern edge the center of the arc of illumination.

Given, therefore, the south side of the Moon naturally brighter and the northwest side abnormally bright by its nearness to the edge of the shadow the darker middle would look like a band which, however, would disappear as the Moon traveled deeper in the Earth's shadow and not re-appear at the end of the eclipse.

Determination of the Mass of Mercury.—Mr. F. E Seagrave calls attention to the close approach of Comet *b*, 1902 to Mercury on 1902, November $29^d\ 17^h$. The heliocentric coördinates of Mercury at that time are $\lambda = 225°\ 6'$, $\beta = +\ 0°\ 14'\ 0''$, $\log r = 9.65328$, and of the comet according to the elements given in the Lick *Bulletin* No. 25, $\lambda = 225°\ 18'$, $\beta = -\ 1°\ 50'\ 40''$, $\log r = 9.63581$. The logarithm of the least distance will therefore be 0.0177, corresponding to a distance of 1,644,000 miles. This result may be checked by the geocentric positions. At November $29^d.5$, the geocentric coördinates of Mercury are R. A. $= 15^h\ 50^m\ 58^s$, Decl. $= -\ 20°\ 1'.6$, $\log \delta = 0.1500$. The coördinates of the comet, according to the ephemeris mentioned above are R. A. $= 15^h\ 53^m\ 23^s$, Decl. $= -20°\ 44'.3$, $\log \delta = 0.1451$. According to Nijland's ephemeris (*A. N.* 160,14), the coördinates of the comet are R. A. $= 15^h\ 54^m\ 54^s$, Decl. $= -\ 20°\ 37'.7$, $\log \delta = 0.1443$. The comet will probably be visible for some time after passing perihelion, as is shown by the following extension of the ephemeris by Mr. Seagrave:

EPHEMERIS.

Date 1902-3	R. A.			Decl.		log *r*.	log Δ.	Br.
	h	m	s	°	′			
Dec. 7.5	15	27	25	−24	12.9	9.7335	0.1296	10.22
11.5	15	15	19	−26	0.2	9.7868	0.1145	8.49
15.5	15	3	13	−27	52.1	9.8368	0.0958	7.35
19.5	14	50	34	−29	50.6	9.8827	0.0739	6.58
23.5	14	36	53	−31	58.2	9.9244	0.0494	6.08
27.5	14	21	13	−34	15.3	9.9622	0.0225	5.78
31.5	14	2	37	−36	41.9	9.9968	9.9939	5.63
Jan. 4.5	13	39	54	−39	15.3	0.0284	9.9642	5.58
8.5	13	11	30	−41	48.0	0.0575	9.9347	5.59
12.5	12	35	54	−44	4.7	0.0844	9.9072	5.60
16.5	11	52	18	−45	39.6	0.1093	9.8842	5.55
20.5	11	1	56	−45	59.7	0.1325	9.8688	5.36
24.5	10	8	59	−44	42.3	0.1543	9.8634	4.97

The effect of the disturbance by Mercury can therefore be determined with such accuracy that it is hoped that it will give a good value of the mass of that planet. In any case careful measures of the position of the comet after November 29 are greatly to be desired.

EDWARD C. PICKERING.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., Oct. 20, 1902.

The Perseid Meteors, August 1902.—The Perseids were observed here on August 10th and 11th, the maximum occurring on the 11th. The sky was clear on both nights except for the period from $9^h\ 26^m$ to $10^h\ 26^m$ on the 10th during which only a few of the brighter stars near Perseus could be seen. The following tables show the distribution as regards time and brightness:

August 10th.

	h m	h m	h m	h m	h m	
	9 26	12 33	13 33	14 33	15 33	
Period.....10	26	13 33	14 33	15 33	16 8	Total
No. Perseids.....	2	11	11	13	7	44
No. other Meteors.....	4	5	6	7	6	28

THE PERSEID METEORS AUG. 10, 1902.

August 11th.

	h m	h m	h m	h m	h m	h m	h m		
	13 38	13 59	14 29	14 59	15 29	15 59			
Period.....13	50	14 29	14 59	15 29	15 59	16 8	Unre-	corded	Total
No. Perseids.....	9	15	15	14	14	6	3		76
No. other Meteors.	4	8	3	1	5	2	3		26

August 10th.

Magnitude	0	1	2	3	4	5
No. Perseids	1	5	9	20	7	2
No. other Meteors	0	4	5	13	5	1

August 11th.

Magnitude	0	1	2	3	4	5	Unrecorded
No. Perseids	6	3	15	26	18	2	12
No other Meteors	0	2	2	4	8	4	

THE PERSEID METEORS, AUG. 11, 1902.

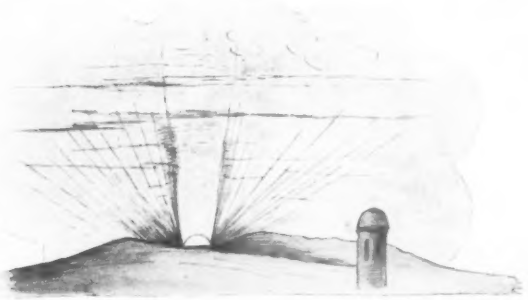
About one-half of the total number of meteors seen are plotted on the accompanying charts. The mean hourly rate of the Perseids for August 10th, not including the first period which is omitted from the estimate on account of clouds was one every 5.0 minutes and for August 11th was one every 1.9 minutes. The color of the brighter Perseids was generally orange. The radiant for August 10th was determined at α 39°.5, $\delta + 56°.7$ and for August 11th was α 46°.8, $\delta + 56°.7$. On August 11th it was very accurately determined by a meteor which was stationary and appeared directly over the 6th magnitude star DM. + 56°798. This meteor with several others close to the radiant gave the above position. A minor radiant was obtained from 3 meteors on the 10th whose position was

α 2°, $\delta + 59°$: and on the 11th one by 3 meteors whose position was α 6°, $\delta + 58°$. These positions probably show the shift of the same radiant. Several meteors were seen on the 10th which if plotted would have radiated from the position given and the same can be said of the position given for the 11th. The place o observation was on the 10th until $13^h\ 33^m$ the lower slit of the dome of the great 26 inch equatorial and after this the top of the dome. On the 11th all were recorded from the top of the dome which gives an unobstructed view in every direction. The constellation Perseus was always the center of observation.

CHARLES P. OLIVIER.

LEANDER MCCORMICK OBSERVATORY,
University of Virginia, Aug. 13, 1902.

Interesting Sunrise Phenomenon.—I have the honor to communicate that on the early morning of November 4th, after I had been observing the beauties of the constellations of Orion and Canis Majoris, I waited for the rising of the Sun, and glad I was for that waiting because I observed a beautiful luminous column which emerged from the Sun between some delicate clouds and



SUNRISE PHENOMENON.
Sketched by PROFESSOR LUIS G. LEON, México, Nov. 4, 1902, $6^h\ 06^m$ A. M.

reached a height of about 15°. All the sky had a pink color, and the column had a bright yellow color. The phenomenon lasted for half an hour.

The temperature at that moment was 5° C., only a little breeze was blowing and right at the east were some *cirru-strati* in which icy particles probably reflected the light of the Sun, causing the phenomenon of the yellow column.

LUIS G. LEON.

MEXICO, November 5, 1902.

The Oxford Photographs.—On Oct. 15 last the measures and reductions of the 1000th plate for the Astrographic Catalogue were completed at the Oxford University Observatory, and a whole holiday was granted in consequence. There are still 180 plates left, but it is hoped to celebrate the completion of the whole before the end of next year.—*The Observatory.*

The Almanac Times of the Eclipses of Jupiter's Satellites.—In response to our letter of inquiry concerning the predicted times of the eclipses of Jupiter's satellites the Director of the Nautical Almanac sends the following statement.

"I am in receipt of your communication of the 10th instant. In reply I beg to state that the time given in the *American Ephemeris* of the eclipses of Jupiter's satellites is the mean of the first and second contacts, and third and fourth contacts, respectively, *i. e.*, the time given for Ec. Dis. is the mean of the first and second contacts, and the time given for Ec. Re. is the mean of the third and fourth contacts." Very respectfully,

WALTER S. HARSHMAN.

Professor of Mathematics, U. S. N.,
Director, Nautical Almanac.

The Great Meteorite of Sinaloa, Mexico.—In the October *American Geologist*, published by N. H. Winchell, geologist for the State of Minnesota, appears a descriptive and fully illustrated article by Henry A. Ward of Rochester, N. Y., on Bacubirito or the Great Meteorite of Sinaloa, Mexico. Mr. Ward has a fine collection of meteorites, and he is much interested in their study; not being able to obtain the information about this very large one he wanted he concluded to visit Mexico for that purpose, and after a long and fatiguing journey he reached Bacubirito, an old mining town on the Rio Sinaloa, in lat. 26° and long. 107° west. The elevation above sea level is about 2000 feet.

The great meteorite was located seven miles due south of that place, near a hamlet called Palmar de la Sepulveda. It was on a farm called Ranchito, in a mountain valley between two spurs of foothills in a corn field close to the eastern edge of the valley. The soil where the meteorite lay imbedded was of vegetable mold, several feet in thickness, and it was covered except one end which projected a little above the general level of the surface. Mr. Ward speaks of it as "a long monstrous boulder of black iron which seemed to be still burrowing to hide itself from the upper world. Its surface form was something like that of a great ham."

By the aid of 28 stout, able bodied men the meteorite was quite fully uncovered, and its dimensions ascertained. It was 13 feet and 1 inch in length, 6 feet and 2 inches wide and 5 feet and 4 inches thick. Mr. Ward thinks this meteorite is the largest and probably the heaviest one yet discovered on our globe. Its form is very irregular, and although measures were taken around its mass at many different points, its cubic contents can not be calculated very accurately. In this connection Mr. Ward mentioned the five largest meteorites now known to science, as follows:

Bemdego (Brazil)	5⅓ tons
San Gregorio (Mexico)	11½ "
Chupaderos (Mexico)	15⅔ "
Anighito (Greenland)	50 "
Bacubirito (Mexico)	50 "

The weights of the first three were ascertained by scales. The last two were estimated.

The inner structure of this meteorite is interesting, for it shows the octahedral system of crystallization in a very marked degree. This feature is rare, only a few others known show it. Many of the faces of the crystals are covered with fine films of taenite which in most cases are of the characteristic bronze yellow color. Acid brings out the Widmanstätten figures in a beautiful manner.

A full description of these crystals are given in the article from which the

above facts are taken, but the analysis of the meteorite made by Professor J. E. Whitfield of Philadelphia should be given. It is as follows:

Specific gravity	7.69	Sulphur	0.005
Iron	88.944	Phosphorus	0.154
Nickel	6.979	Silicon	trace
Cobalt	0.211		

A piece of this meteorite was detached from the parent mass weighing 11 pounds. It was polished and etched showing the Widmanstätten figures and it has been placed in the Ward-Coonley collection of meteorites now on display (on deposit), in the American Museum of Natural History in New York City.

The Leonid Meteors for 1902.—There was no opportunity at Goodsell Observatory for observing the Leonid meteors this year, because of steadily clouded skies during the usual time of display last month. The same unfavorable skies prevailed generally, probably, for we have received very little information from other sources which usually give careful attention to these observations.

Professor Winslow Upton, Director of Ladd Observatory of Brown University, wrote Nov. 18: Cloudy weather prevailed here on the 13th, 14th, 15th and part of the 16th insts., 12^h-14^h astronomical time. One Leonid was seen at $13^h\ 41^m$ on the 16th by two observers. There were occasional rifts in the clouds on the 15th but no meteors were seen.

Comet Temple-Swift.—The following ephemeris comes to hand too late to be put in its proper place with Comet Notes. It is an extension by Mr. J. Bossert of that given in *A. N.* 3811:

Paris Midn.	α			δ		log *r*	log Δ
	h	m	s	°	′		
Nov. 10	20	3	45	−16	6.2	0.1697	0.1596
15		14	42	15	26.6	1591	1603
20		26	19	14	42.2	1486	1606
25		38	35	13	52.6	1383	1603
30	20	51	29	12	57.5	1282	1595
Dec. 5	21	4	57	11	56.3	1184	1584
10		19	0	10	49.5	1089	1566
15		33	38	9	36.7	1000	1546
20		48	51	8	17.4	0917	1525
25	22	4	35	6	52.0	0843	1502
30	22	20	51	5	21.0	0.0776	0.1479

Circular No. 53 of the Central Station,
Kiel, 1902, Nov. 8.

Differential and Integral Calculus by Snyder and Hutchinson.—This new book follows the plan of the Differential Calculus by McMahon and Snyder published in 1898 and that of the Integral Calculus by Murray published in the same year. This new course is a briefer one, in one book of 320 pages instead of two books of 337 and 283 pages respectively, which constitutes the longer course by the authors just named. We have used the longer course for some time and find it excellent, but too long for the time that can be allotted to it, in the ordinary scientific course as it is at present planned in Carleton College. The time now given to the study of the Calculus, Differential and Integral, is twenty-five weeks, aggregating 111 recitation hours, giving to the Differentia 14 weeks of 4 hours each and to the Integral 11 weeks of 5 hours each. In this time we have been able to do something over one-half of the entire work con-

tained in both books including the long lists of exercises and problems in almost every chapter.

This longer course was planned by its authors as one needed for a thorough preparation to enter the engineering courses at Cornell University. It is admirably adapted to this end as far as we know; and any student who can give about one year's time to this study as taken in college and will master this course will certainly be well fitted in Calculus for advanced studies in mathematics in almost any line of scientific work he may choose to pursue.

In the same way this new book, before us, will give to the ordinary college class the amount of training well adapted for general instruction, where the aim is a knowledge of the branch for its own sake, or a beginning for further study, or a drill in mathematical methods that will aid in preserving a balance in the mental equipment of a liberal education. The strong points in all the books presenting these courses are: The clear and complete demonstrations, the rigid method of limits, the large number of well-chosen exercises, the exact definition and the strictly scientific bearing of the whole treatment of this important branch of mathematics.

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